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ABSTRACT

This second-year student manual contains 140 brief related science lessons applying science and math to trade activities in the field of stationary engineering. The lessons are organized into 16 units: (1) Introduction to Stationary Engineering, (2) Engineering Fundamentals, (3) Steam Boilers, (4) Boiler Fittings, (5) Boilerroom System, (6) Feed-Water Accessories, (7) Steam Accessories, (8) Fuels, (9) Combustion Accessories, (10) Combustion, (11) Boiler Plant Instruments, (12) Boiler Water Conditioning, (13) Compressed Air System, (14) Electrical Systems, (15) Operation, and (16) Service and Maintenance. Each lesson includes objectives, textual information (sometimes including diagrams or other illustration), list of references, and assignment(s). (Lesson plans for the teacher are in a separate volume, "Stationary Engineering. Science 2. Teachers Guide.") (HD)

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State of New Jersey
Department of Education
Division of Vocational Education

STATIONARY ENGINEERING SCIENCE MANUAL-2

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INTRODUCTION

These assignments relate science to the field of Stationary Engineering. An understanding of the related science and math involved in Stationary Engineering is important. These lessons are brief, but they include a wide range of activities in which science is applied to the trade activities. Some of the activities involve math, so both the math and the science are applied to the trade activities when needed.

Stationary Engineering is a very important trade. Many people depend on the Stationary Engineer. Prepare yourself well, so that they will be able to depend on you when your knowledge and skills are needed.

Objective: 1. Be able to recognize industrial safety practices and procedures.

Information: Most large industrial plants will have safety engineers. Their job is to inspect the plant and set up safe operating procedures. Industrial accidents are costly and must be eliminated or at least kept to a minimum. The federal government has entered the field of safety by establishing OSHA. OSHA as a governmental agency that will inspect any and all industrial facilities. Unsafe practices or equipment are dealt with severely. They have the authority to levy fines and they do not hesitate to use this authority. You must become familiar with OSHA and their requirements. They are available from the government.

Reference: OSHA Manual

Assignment:

1. Why do you feel the federal government established OSHA?
2. Do you think there is an advantage in having an agency like OSHA?
3. Look through some trade journals or newspapers for information on OSHA.

Objectives:

1. Be able to protect your job from fire.
2. Be able to organize a first aid fire brigade.

Information: Insurance statistics state that there are about 400 industrial fires per day in the United States. You may say "so what, big deal – how does that affect me?" Well,every time there is an industrial fire, people are out of work. Some are out of work just for a short time, but some plants destroyed by fire never reopen. It could happen to you! Knowing how to protect your plant from fire helps protect your own home and family. Your own security is at stake.

There are three general classes of fires:

1. Class A – covering wood, paper, textiles, and other ordinary combustible material containing carbon.
2. Class B – oil, gas, grease, paint, or any other liquid that will gasify when heated.
3. Class C – electrical fires, motors, switches, and transformers.

It should be mentioned here that a new class of fire has been added because of our advanced space age technology. It is:

4. Class D – This covers fires in combustible metals such as zirconium, titanium, magnesium, sodium, or potassium. A special powder is used and may be applied by a scoop or shovel.

It is your responsibility to know where every first aid fire extinguisher is located in your area of the plant. You should also know what type of extinguisher is used for each class of fire and how to use each type of extinguisher.

Reference: *Training Your Fire Brigade,* Walter Kidde Co.

Assignment: After having read the reference, answer the following questions. Be prepared to discuss the questions in class.

1. Discuss the four classes of fires and what they cover.
2. Explain why plant fire prevention is protecting your security.
3. Discuss how to set up a plant first aid fire brigade.
4. Briefly discuss the duties of a fire brigade chief.

Objective: Be able to describe why good housekeeping is important to safety.

Information: Good housekeeping is one of the best ways to prevent fires. You do not have to be an engineer to know how to establish good housekeeping habits; it just takes common sense. The key to good housekeeping is good habits. If everyone in the boilerroom or engineroom develops good work habits, housekeeping is easy. The chief engineer must set standards that must be followed by everyone. If he insists that these standards be carried out on all shifts, they will be. For example, oil spills must be wiped up at once. If a valve is leaking oil, fix it or stand there and keep cleaning up the leak. Which is easier to do? All rags are to be stored in safety waste cans. Used oily rags are to be kept in proper waste containers and emptied every shift. No highly volatile liquids will be used for cleaning parts or equipment in the boilerroom or engineroom at any time. Varsol or similar cleaning agents are to be stored in safety cans only. All paint will be stored in approved paint lockers only. This list of housekeeping needs can be expanded to suit any plant needed.

If the chief engineer develops a list of this type with the aid of plant safety personnel and union representatives and has it properly posted, it could mean your job if you continually fail to comply with it.

Assignment:

1. Why should oily rags be stored in safety containers?
2. Discuss what is meant by spontaneous combustion.
3. What is a volatile liquid?
4. Why do you think it would be important to clean up oil spills at once?
5. Do you think it would be fair to discharge a man for continually ignoring good housekeeping practices? Explain your answer.

Engineering Department Responsibility — Assignment 1-B-1

Objective: Be able to describe the organization chart of an Engineering Department.

Information: The Engineering Department in most industrial plants must operate 24 hours a day, 7 days a week, 365 days a year. They are responsible for providing the plant with the steam, water, air, refrigeration, and sometimes electrical power needed for plant process. A sample organization chart is attached to give you some idea of how the chain of command works.

The Mechanical Inspection Bureau requirements are as follows:

1. Plants with over 3,000 boiler horsepower require a Gold Seal Engineer as chief.
2. Plants with 1,001 to 3,000 boiler horsepower require at least a Red Seal Engineer as chief.
3. Plants with 501 to 1,000 boiler horsepower require at least a Blue Seal Engineer as chief.
4. Plants with up to 500 boiler horsepower need at least a High-Pressure Black-Seal-in-Charge license as chief.

A High-Pressure Black Seal Fireman-in-Charge license also allows you to be in charge of your own shift under a properly licensed chief engineer in plants up to 1,000 boiler horsepower. Anything over 100 boiler horsepower requires the fireman to have a licensed engineer on shift with him.

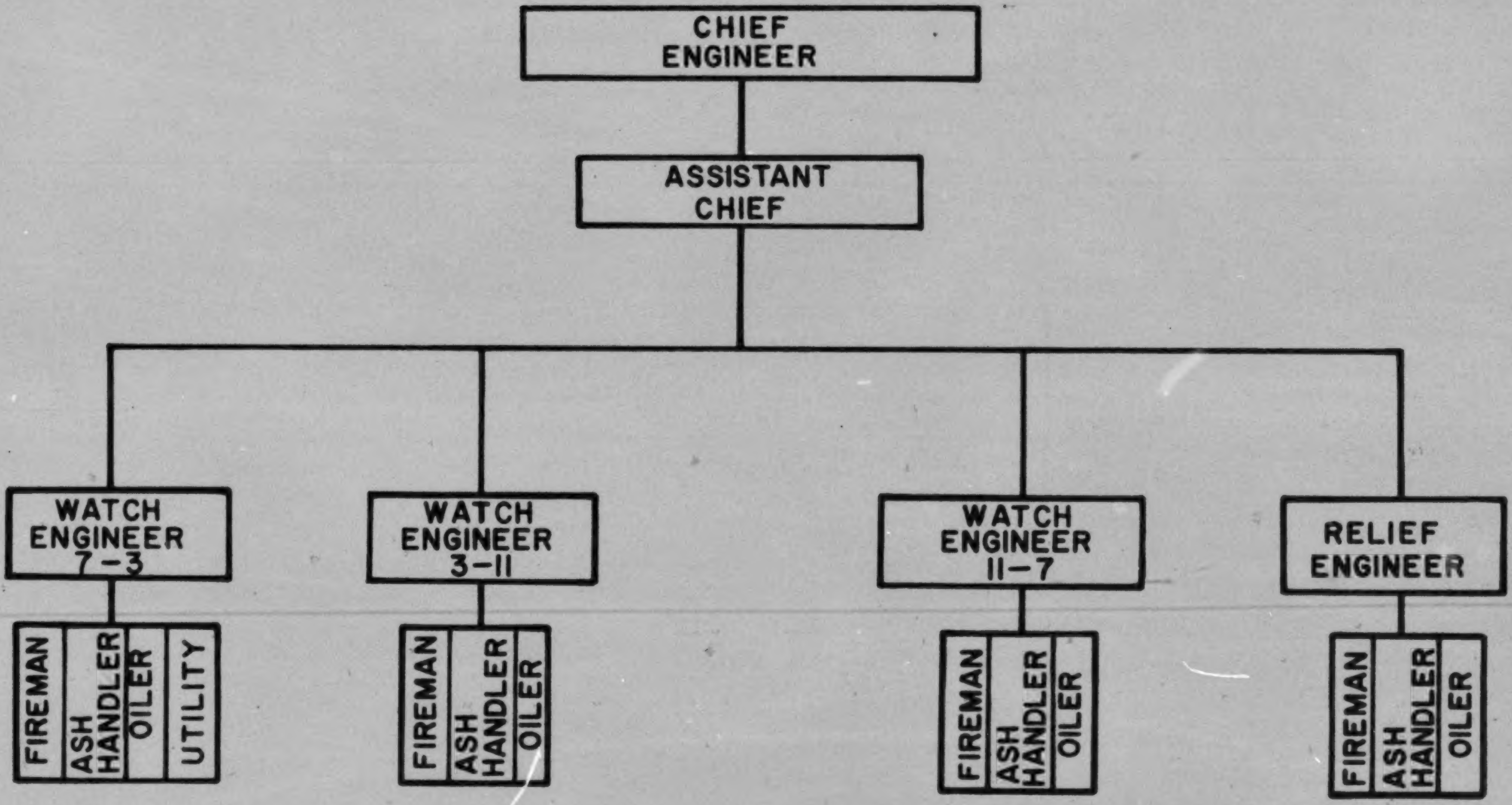
It should be easy to see that as the plant size increases and the equipment becomes more sophisticated, a higher grade of license is required to be in charge.

The rules and regulations of the Mechanical Inspection Bureau will be covered in detail in later lessons.

Reference: *Rules and Regulations,* Mechanical Inspection Bureau

Assignment:

1. What duties can be performed by a person holding a Black Seal High-Pressure Fireman-in-Charge license?
2. Discuss the Mechanical Inspection Bureau's requirements for chief engineers.
3. Discuss the penalties if any, for operating a plant with improper licenses.


CHIEF ENGINEER
ASSISTANT CHIEF
WATCH ENGINEER 7-3
WATCH ENGINEER 3-11
WATCH ENGINEER 11-7
RELIEF ENGINEER
FIREMAN
ASH HANDLER
OILER
UTILITY
FIREMAN
ASH HANDLER
OILER
FIREMAN
ASH HANDLER
OILER
FIREMAN
ASH HANDLER
OILER

Objectives:

1. Be able to define pressure and the units used to express it.
2. Be able to define work and the units used to express it.
3. Be able to define power and the units used to express it.

Information: Remember last year's assignments on pressure, work, and power. This is a quick review of the relationship of pressure, work, and power. First, we will review the definitions and the units of measurement. Then our next assignment will use the pressure – work – power relationship in solving problems.

"Pressure" – Pressure is defined as a force applied per unit of force. You can compute pressure if you know the force applied and the area that the force is applied to.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

For example, if a force of 1000 pounds is applied to an area of 6 square inches, The pressure is:

$$\text{Pressure} = \frac{\text{1000 lbs. force}}{\text{5 sq. inches of area}} = \text{200 pounds per square inch}$$

The stationary engineer will normally find most pressure gages calibrated in pounds per square inch (p.s.i.). However, pressure can also be measured in ounces per square inch or tons per square foot.

Most gages will read zero p.s.i. at atmospheric pressure. Remember, this reading is not the absolute or true pressure. It does not include atmospheric pressure (usually 14.7 p.s.i.). Absolute pressure is the gage reading plus the pressure of the atmosphere.

Absolute Pressure = Gage Reading + Atmospheric Pressure

Work – Work is defined as a force acting on a body and moving it a distance. The amount of work is the product of the force and the distance moved.

Work = Force × Distance

Work is usually measured in foot pounds (ft. lbs.). For example, if a force of 100 lbs. moves an object 8 feet, the work done equals force times distance.

Work = 100 lbs. force × 8 ft. distance
Work = 800 ft. lbs.

Power – Power is defined as the rate of doing work. The units used are foot-pounds and time. We know that work is measured in foot-pounds. If we use minutes as a unit of time, then power will equal work per minute shown as ft. lbs. per minute

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

For example, if we move 20,000 ft. lbs. in 1 minute, power equals :

$$\text{Power} = \frac{\text{20,000 ft. lbs. of work}}{\text{1 minute of time}} = \text{20,000 ft. lbs./min.}$$

Power is often measured in horsepower. One horsepower equals 33,000 ft. lbs. per minute. If 33,000 ft. lbs. of work is done in 1 minute, we have:

$$\text{Power} = \frac{\text{33,000 ft. lbs.}}{\text{1 minute}} = \text{33,000 ft. lbs./min.} = \text{1 horsepower (hp.)}$$

References:
1. *Steam Plant Operation*
2. *Elementary Steam Power*

Assignment:
1. What is pressure?
2. What units are used to express pressure?
3. Define gage pressure and absolute pressure.
4. Define atmospheric pressure.
5. Define work.
6. What units are used to express work?
7. Define power.
8. Define horsepower.
9. How does work and time relate to power?
10. How does power relate to horsepower?
11. Set up and solve a problem involving work, time and horsepower.

Pressure Problems **Assignment 2-A-1-M1**

Objective: Be able to use the pressure-force-area relationship in solving problems.

Information: Pressure is defined as a force applied per unit of area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

If the force acting on a given area is known, then you can find the pressure. For example, a force of 1000 pounds is applied to an area of 4 square inches. What is the pressure?

$$\text{Pressure} = \frac{\text{1000 lbs. of force}}{\text{4 sq. in. of area}} = \text{250 p.s.i.}$$

You can also find the area when the pressure and the force are known. For example, the force is 1500 lbs. and the pressure is 100 p.s.i. What is the area that the force is acting on?

$$\text{Area} = \frac{\text{1500 lbs. of force}}{\text{100 p.s.i. of pressure}} = \text{250 p.s.i.}$$

It is also possible to find the force if the pressure and area are known. For example, a tank has base dimensions of 6 ft. by 12 ft. and a pressure of 3 p.s.i. What is the force?

First, convert the area to square inches:

6 X 12 = 72 square feet
72 sq. ft. X 144 = 10368 square inches

Force = Pressure X Area
Force = 3 p.s.i. X 10368 sq. in. = 31104 pounds

Assignment:

1. Find the force on a safety valve disk that has an area of 6.25 square inches and is connected.
2. Find the area of a flat surface that has a force of 1000 pounds and produces a pressure of 12. p.s.i.
3 What is the pressure on the top of a compressor piston if the force is 20,000 pounds and the area of the piston is 85 square inches?

Objective: Be able to use pressure conversion factors.

Information:

1. The pressure at the base of a column will be .0361 p.s.i. for every vertical inch of water, or .433 p.s.i. for every vertical foot of water. (See Figure 2-A-1-M2-1)

2. The pressure at the base of a column will be .491 p.s.i. for every vertical inch of mercury, or 5.892 for every vertical foot of mercury. (See Figure 2-A-1-M2-2.)

3. To change gage pressure to absolute pressure, add 14.7 p.s.i. (atmospheric pressure). Check results on Figure 2-A-1-M2-2.

4. To convert a vacuum reading to absolute pressure, multiply the reading by .491 and subtract it from 14.7 p.s.i. (atmospheric pressure). Check results on Figure 2-A-1-M2-2.

Examples:

1. A boiler pressure gage mounted on a panel board is located 30 feet below the boiler drum. With no pressure on the boiler, what pressure would the gage indicate?

   Pressure = Vertical ft. X .431 p.s.i. per foot
   Pressure = 30 X .433 = 12.99 p.s.i.

2. A boiler pressure gage reads 150 p.s.i. What would this be in p.s.i.a. (pounds per square inch absolute)?

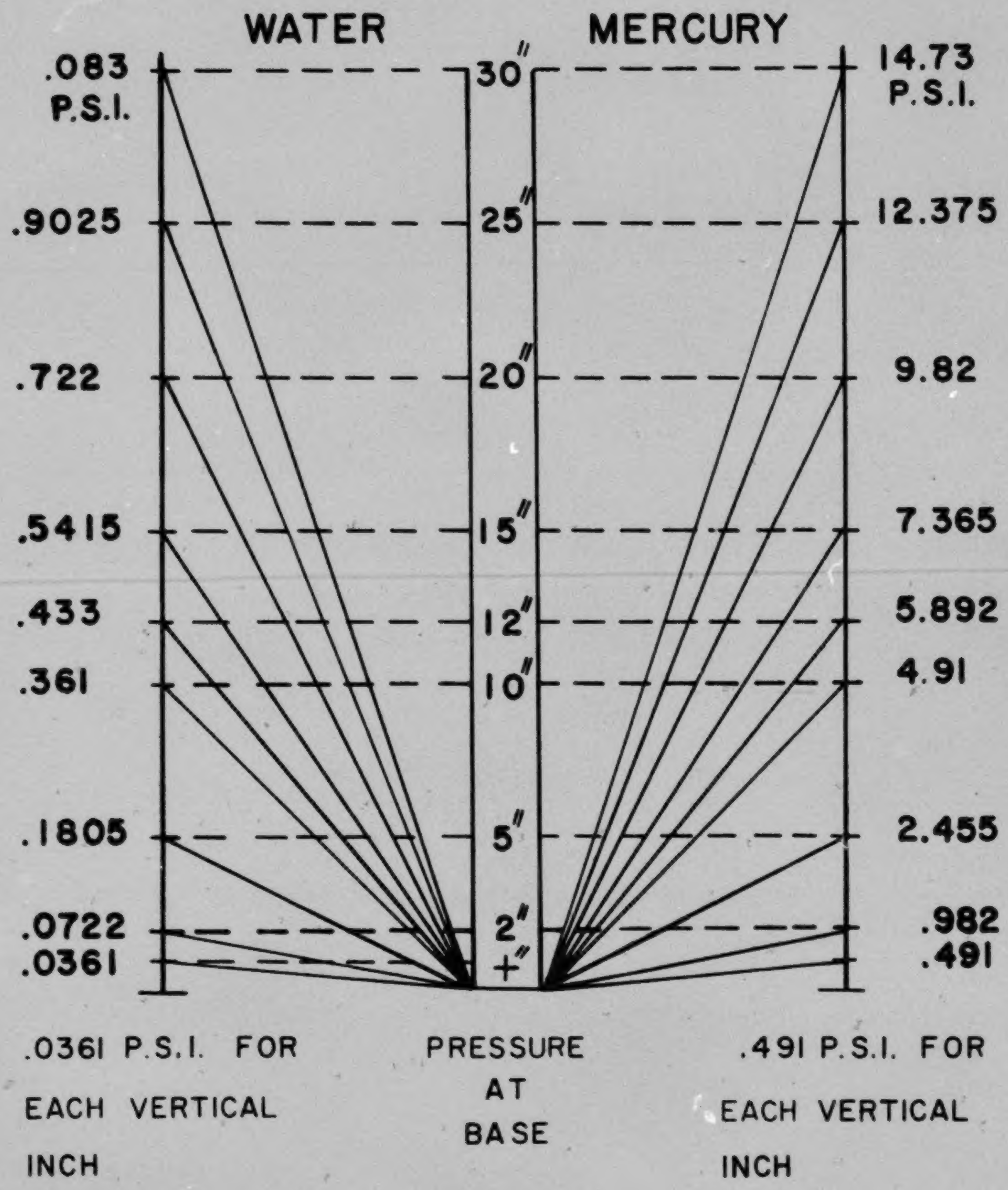
   Absolute Pressure = gage pressure + 14.7
   Absolute Pressure = 150 + 14.7
   Absolute Pressure = 164.7 p.s.i.a.

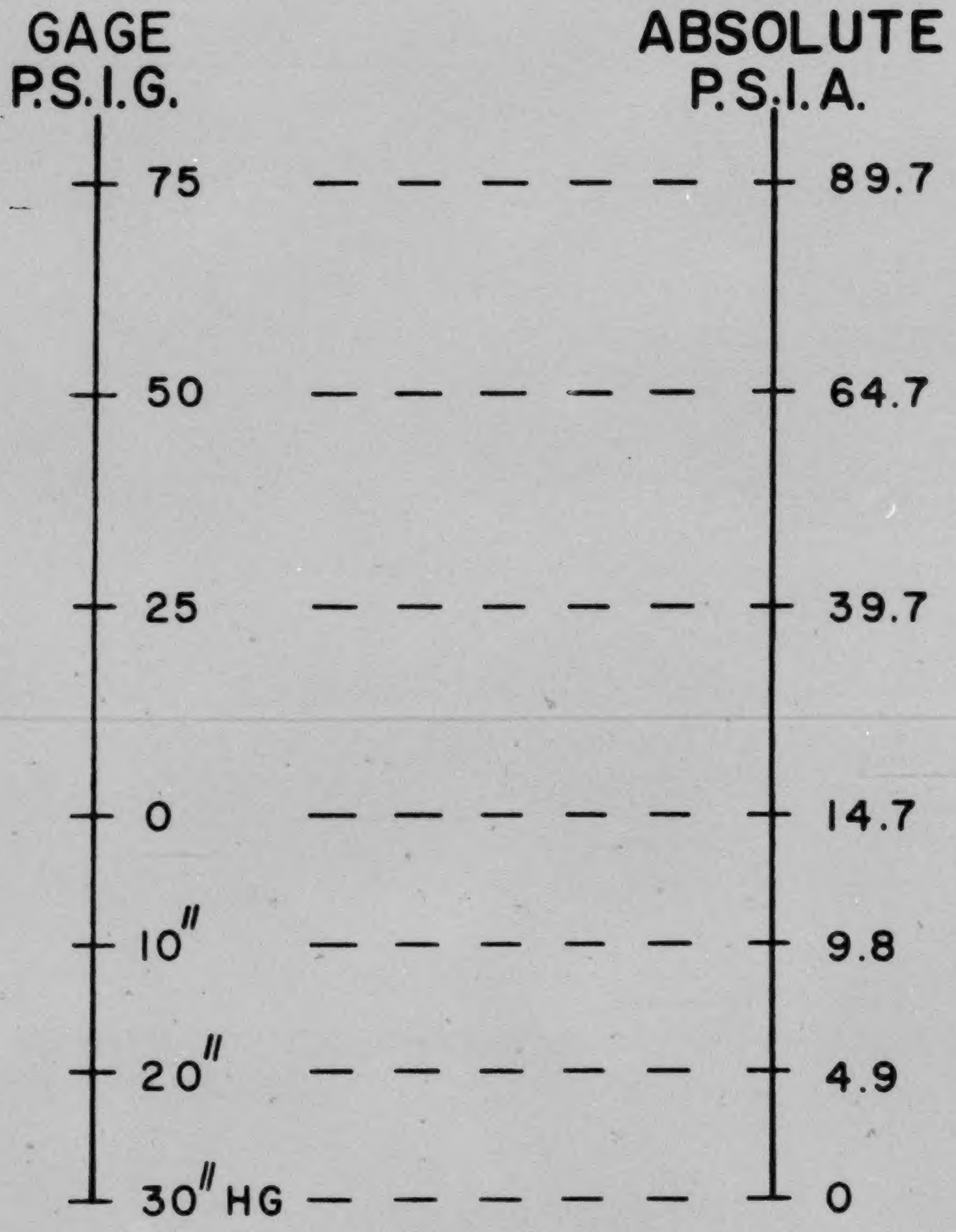
3. A fuel oil suction gage reads 7.5 inches of vacuum. What would this be in absolute pressure?

   Absolute Pressure = 14.7 - (Vacuum X .491)
   Absolute Pressure = 14.7 - 7.5 X .491
   Absolute Pressure = 14.7 - 3.68 = 11.02 p.s.i.a.

Assignment:

1. A column of mercury 15" high would exert how much pressure at its base?
2. A turbine exhausts into a condenser carrying a 29" vacuum. What is the absolute pressure in the condenser?


WATER
MERCURY
.083 P.S.I.
.9025
.722
.5415
.433
.361
.1805
.0722
.0361
30"
25"
20"
15"
12"
10"
5"
2"
+"
14.73 P.S.I.
12.375
9.82
7.365
5.892
4.91
2.455
.982
.491
.0361 P.S.I. FOR EACH VERTICAL INCH
PRESSURE AT BASE
.491 P.S.I. FOR EACH VERTICAL INCH



GAGE PRESSURE TO ABSOLUTE PRESSURE CONVERSION CHART

Work and Power Problems — Assignment 2-A-1-M3

Objectives:

1. Be able to solve problems involving work.
2. Be able to solve problems involving power.

Information: Work is defined as a force acting on a body and moving it a distance.

$$\text{Work} = \text{Force} \times \text{Distance}$$

The force is usually measured in pounds and the distance in feet. That gives an answer in foot pounds.

For example, a force of 100 pounds is applied and moves an object 80 feet. How many foot-pounds of work was done?

$$\text{Work} = \text{Force} \times \text{Distance}$$
$$\text{Work} = 100 \text{ lbs.} \times 80 \text{ ft.} = 8{,}000 \text{ ft. lbs.}$$

Power is the rate of doing work. It is the work done in a unit of time.

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

For example, if an engine does 140,000 ft. lbs. of work in 4 minutes, how much power was developed?

$$\text{Power} = \frac{140{,}000 \text{ ft. lbs.}}{4 \text{ min.}} = 35{,}000 \text{ ft. lbs. per min.}$$

A horsepower is defined as 33,000 ft. lbs. of work per minute.

$$\text{Horsepower} = \frac{\text{Power}}{33{,}000} = \frac{35{,}000}{33{,}000} = 1.06 \text{ hp.}$$

Assignment:

1. How much work is done when a 500 lb. safe is moved 20 ft?
2. What horsepower is needed to lift a 4-ton beam 60 ft. in 4 min?
3. What horsepower is needed for an elevator to lift 4,800 lbs 220 ft. in 2½ min.?
4. If an engine can do 68,000 ft. lbs. of work in 2½ minutes, what is its horsepower?

Objective : Be able to calculate both the old and new methods of determining boiler horsepower.

Information: Boilers are rated in horsepower. Not too many years ago the boiler horsepower was determined by the number of square feet of heating surface that a boiler contained. For example:

1. In water tube boilers, 10 sq. ft. of heating surface equaled 1 boiler horsepower.
2. In horizontal firetube boilers, 12 sq. ft. of heating surface equaled 1 boiler horsepower.
3. In vertical firetube boilers, 14 sq. ft. of heating surface equaled 1 boiler horsepower.

In modern package boilers, some companies claim to have boilers that will produce 1 boiler horsepower for every 5 sq. ft. of heating surface. Now, how do we determine horsepower?

Well, out goes square feet of heating surface and in comes pounds of steam produced per hour. That's right. We changed the rules. Now, a horsepower equals the evaporation of 34.5 pounds of water per hour from and at 212°F.

This new method of determining boiler horsepower was fine except for two things. First, boilers do not operate with steam-water temperatures of 212°F. Second the feed-water temperature is not always 212°F. as it enters the boiler. So a correction factor known as the Factor of Evaporation was needed. By using the factor of evaporation, you can determine the boiler horsepower being developed on a boiler at any given time.

So,

$$\text{Developed Boiler Horsepower} = \frac{\text{Lbs. of steam per hour} \times \text{Fact. or Evap.}}{34.5}$$

A boiler horsepower is equivalent to 33,475 Btu's. This is a result of multiplying 970.3 Btu's (the Btu's needed for latent heat evaporation) times 34.5 (pounds of water evaporated per hour from and at 212°F. for 1 horsepower.

$$\text{BHP} = 970.3 \text{ Btu} \times 34.5 = 33{,}475 \text{ Btu's}$$

Assignment:
1. Define a boiler horsepower.
2. How is the boiler capacity rated in modern practice?
3. How many Btu's is a boiler horsepower equivalent to?
4. Why do you think that the square feet of heating surface method of calculating boiler horsepower is no longer used?
5. What is the Factor of Evaporation and how is it used?

Objective: Be able to find the factor of evaporation of a boiler.

Information: To solve a problem involving developed boiler horsepower, we need to know how to find the factor of evaporation of the given boiler. It can be found using this formula.

$$\text{Factor of Evaporation} = \frac{H_g - (T_{FW} - 32)}{970.3}$$

Where:

H_S is the heat in one pound of saturated steam.

T_{FW} is the temperature of the feedwater as it enters the boiler drum.

The number 32 is the base temperature of 32°F. from which we calculate total heat.

970.3 is the latent heat of vaporization of water.

Examples:

1. Find the factor of evaporation of a boiler that produces steam at 400 p.s.i. that contains 1204.5 Btu's per pound. The feed-water temperature entering the boiler is 190°F.

$$\text{Factor of Evap.} = \frac{H_S - (T_{FW} - 32)}{970.3}$$

$$\text{Factor. of Evap.} = \frac{1204.5 - (190-32)}{970.3}$$

$$\text{Factor of Evap.} = \frac{1204.5 - 158}{970.3} = 1.078$$

2. Find the factor of evaporation if the pressure is 120 p.s.i. with a heat content of 1190.4 Btu and a feed-water temperature of 210°F.

$$\text{Factor of Evap.} = \frac{H_S - (T_{FW} - 32)}{970.3}$$

$$\text{Factor of Evap.} = \frac{1190.4 - (210-32)}{970.3}$$

$$\text{Factor of Evap.} = \frac{1190.4 - 178}{970.3} = 1.043$$

References: *Steam Plant Operation*
Elementary Steam Power

Assignment:

1. A boiler produces steam at 15 p.s.i. that contains 1150.8 Btu's per pound. The feed water is 170° F. Find the factor of evaporation.

2. Find the factor of evaporation with the following conditions.

	Steam Pressure	H_s - Btu	Temp. Fw
a.	40 p.s.i.	1169.7 Btu	200° F
b.	100 p.s.i.	1187.2 Btu	165° F
c.	350 p.s.i.	1203.9 Btu	220° F
d.	200 p.s.i.	1198.4 Btu	160° F
e.	130 p.s.i.	1191.7 Btu	140° F
f.	250 p.s.i.	1201.1 Btu	185° F

Objectives:
1. Be able to find the rated horsepower of a boiler.
2. Be able to find the developed horsepower of a boiler.

Information: The definition of a boiler horsepower is "the evaporation of 34.5 pounds of water per hour from and at 212°F." From this definition we can set up the following equation.

$$\text{B. HP} = \frac{W_s}{34.5}$$

Where:

W_s = pounds of steam per hour

34.5 = pounds of water per hour evaporated from and at 212°F for 1 boiler horsepower

Examples:

Example 1. A boiler produces 35,000 pounds of steam per hour. Find the boiler horsepower.

$$\text{B. HP.} = \frac{W_s}{34.5}$$

$$\text{B. HP.} = \frac{35{,}000}{34.5}$$

$$\text{B. HP.} = 1014$$

This would be considered as rated boiler horsepower.

To find the developed boiler horsepower, it is necessary to introduce the factor of evaporation as discussed in our previous lessons. It would change our equation to:

$$\text{B. HP.} = \frac{W_s \times \text{Fact. of Evap.}}{34.5}$$

Example 2. A boiler evaporates 10,000 pounds of steam per hour with a factor of evaporation of 1.24. Find the developed boiler horsepower.

$$\text{B. HP.} = \frac{W_s \times \text{Fact of Evap.}}{34.5}$$

$$\text{B. HP.} = \frac{10{,}000 \times 1.24}{34.5} = 359.42$$

Example 3. A boiler generates 5500 pounds of steam per hour with a factor of evaporation of 1.078. Find the developed boiler horsepower.

$$\text{B. HP.} = \frac{W_S \times \text{Fact. of Evap.}}{34.5}$$

$$\text{B. HP.} = \frac{5500 \times 1.078}{34.5}$$

$$\text{B. HP.} = 171.85$$

If the factor of evaporation is not known directly it is possible to solve for the developed boiler horsepower in one step rather than two.

$$\text{B. HP.} = \frac{W_S \times \text{Fact. of Evap.}}{34.5}$$

$$\text{Substitute} \; - \; \frac{H_S - (T_{FW} - 32)}{970.3} \quad \text{For Fact. of Evap.}$$

$$\text{B. HP.} = \frac{W_S \times \frac{[H_S - (T_{FW} - 32)]}{970.3}}{34.5}$$

$$\text{B. HP.} = \frac{W_S\,(H_S - T_{FW} + 32)}{34.5 \times 970.3}$$

$$\text{B. HP.} = \frac{W_S\,(H_S - T_{FW} + 32)}{33{,}475}$$

You will note that in the above equation you are actually finding the total heat (Btu's) being put out by the boiler per hour, and then dividing that total by 33475 which is the number of Btu's in one boiler horsepower.

Example 4. A boiler evaporates 30,000 pounds of steam per hour. The steam pressure is 130 p.s.i. and has a Btu content of 1191.7 Btu's per pound. The feed water temperature is 210°F. Find the boiler horsepower.

$$\text{B. HP.} = \frac{W_S(H_S - T_{FW} + 32)}{33{,}475}$$

$$\text{B. HP.} = \frac{30{,}000\ (1191.7 - 210 + 32)}{33{,}475}$$

$$\text{B. HP.} = \frac{30{,}000 \times 1013.7}{33{,}475}$$

$$\text{B. HP.} = 908.469$$

References: *Steam Plant Operation*
Elementary Steam Power.

Assignment:

1. A boiler produces 25,000 pounds of steam per hour. Find its rated boiler horsepower.
2. A boiler is rated at 500 hp. How many pounds of steam per hour will the boiler produce?
3. A boiler evaporates 20,000 pounds of steam per hour with a factor of evaporation of 1.19. Find the boiler horsepower.
4. A boiler generates 30,000 pounds of steam per hour with a factor of evaporation of 1.93. Find the developed boiler horsepower.
5. A boiler produces 9100 pounds of steam per hour at 150 p.s.i. It has a Btu content of 1194.1 Btu per pound and the feed water entering the drum is 172°F. Find the developed boiler horsepower.

Objectives:

1. Be able to define heat.
2. Be able to define latent heat, sensible heat, latent heat of fusion, and latent heat of evaporation.
3. Be able to describe how heat is measured and transmitted.

Information: Heat is a form of energy due to the molecules within a substance being in motion. We say that this is a form of kinetric energy because of the molecular motion.

There are three states a substance can be in – solid, liquid, or gas. In each case, the state of the substance is dependent on the amount of heat within the substance. If the heat is added or removed from a substance, there can be a change of state.

Heat is measured in two ways –

1. The intensity is measured with a thermometer or an instrument that will measure temperature.
2. The quantity of heat in a substance is the number of B.t.u. (British thermal units) it has in it. A B.t.u. is the heat necessary to change the temperature of one pound of water one degree Fahrenheit.

Now, let's define some terms that will be helpful in our course of study.

1. Latent Heat - hidden heat. It will change the state of a substance but not its temperature.
2. Sensible Heat – Can be felt and measured with a thermometer. It will change the temperature of a substance but not its state.
3. Latent Heat of Fusion – Btu's necessary to change one pound of ice at 32°F. to one pound of water at 32°F.
4. Latent Heat of Evaporation – Btu's necessary to change one pound of water at 212°F. to one pound of steam at 212°F.

Heat is transmitted in three ways and flows from the hot to cold.

1. Conduction is when molecules come into direct contact with each other and heat energy is passed from one to the other.
2. Convection is when heat is transmitted by currents in a fluid such as air or water.

3. **Radiation** is when heat is transmitted in a wave motion such as the heat from the sun.

Heat can be converted to other forms of energy. The mechanical equivalent of heat is 778 foot pounds per Btu. So, Btu can be converted to foot pounds. It is possible to convert to other forms of energy.

References: *Elementary Steam Power Engineering*
Steam Plant Operation

Assignment:

1. Define heat.
2. Describe how heat causes molecular motion.
3. Define the British thermal unit (Btu).
4. Explain latent heat of fusion and evaporation.
5. Define temperature.
6. Define sensible heat.
7. What are the meanings of the terms intensity of heat and quantity of heat?
8. What is the mechanical equivalent of heat?
9. How can we use the mechanical equivalent of heat?
10. What are the methods of heat transmission?
11. Explain each method of heat transmission.
12. How many Btu's are required to change the following?
    a. One pound of ice at 32°F. to water at 32°F.
    b. To raise the temperature of one pound of water at 32°F. to water at 212°F.
    c. One pound of water at 212°F. to steam at 212°F.

1 # ICE 32° F + LATENT HEAT FUSION 1 # WATER 32° F = 144 B.T.U.

1 # WATER 32° F + SENSIBLE HEAT 1 # WATER 212° F = 180 B.T.U.

1 # WATER 212° F + LATENT HEAT EVAPORATION 1 # STEAM 212° F = 970.3 B.T.U.

BTU CHART

2-C-1-1

Objectives:

1. Be able to convert Fahrenheit, Centigrade, Rankine temperatures from one scale to another.
2. Be able to convert Btu's to foot-pounds and foot-pounds to horsepower.

Information: There are times when it is necessary to convert Fahrenheit degrees to centigrade degrees or centigrade to Fahrenheit degrees. It also becomes necessary to convert Fahrenheit degrees to Rankine degrees. To change °F to °C, you can use the following equation:

$$^{\circ}C = \frac{^{\circ}F - 32}{1.8}$$

Example 1: Convert 140°F to °C.

$$^{\circ}C = \frac{^{\circ}F - 32}{1.8} = \frac{140 - 32}{1.8} = 60^{\circ}C$$

To change °C to °F you use the following equation

$$^{\circ}F = (^{\circ}C \times 1.8) + 32$$

Example 2: Convert 60° to °F.

$$^{\circ}F = (^{\circ}C \times 1.8) + 32$$

$$^{\circ}F = (60 \times 1.8) + 32$$

$$^{\circ}F = 108 + 32 = 140^{\circ}F$$

To change °F to °R, you use the following equation.

$$^{\circ}R = ^{\circ}F + 460^{\circ}$$

Example 3: Convert 212°F to degrees Rankine.

$$^{\circ}R = ^{\circ}F + 460^{\circ}$$

$$^{\circ}R = 212 + 460 = 672^{\circ}R$$

Example 4: Convert 672° Rankine to the Fahrenheit scale.

$$^\circ F = {}^\circ R - 460$$

$$^\circ F = 672 - 460 = 212^\circ F$$

It has been determined through experiments that one Btu is equivalent to 778 foot lbs. of mechanical energy. This is known as the mechanical equivalent of heat. To convert Btu's to foot pounds you have to multiply Btu's X 778.

Foot pounds = Btu X 778 and to convert foot pounds to Btu's you have to divide foot pounds by 778.

$$\text{Btu} = \frac{\text{Foot-pounds}}{778}$$

Example 5: The total amount of heat 1 lb. of steam is as it leaves the boiler is 1200 Btu per pound. What would this be in foot pounds?

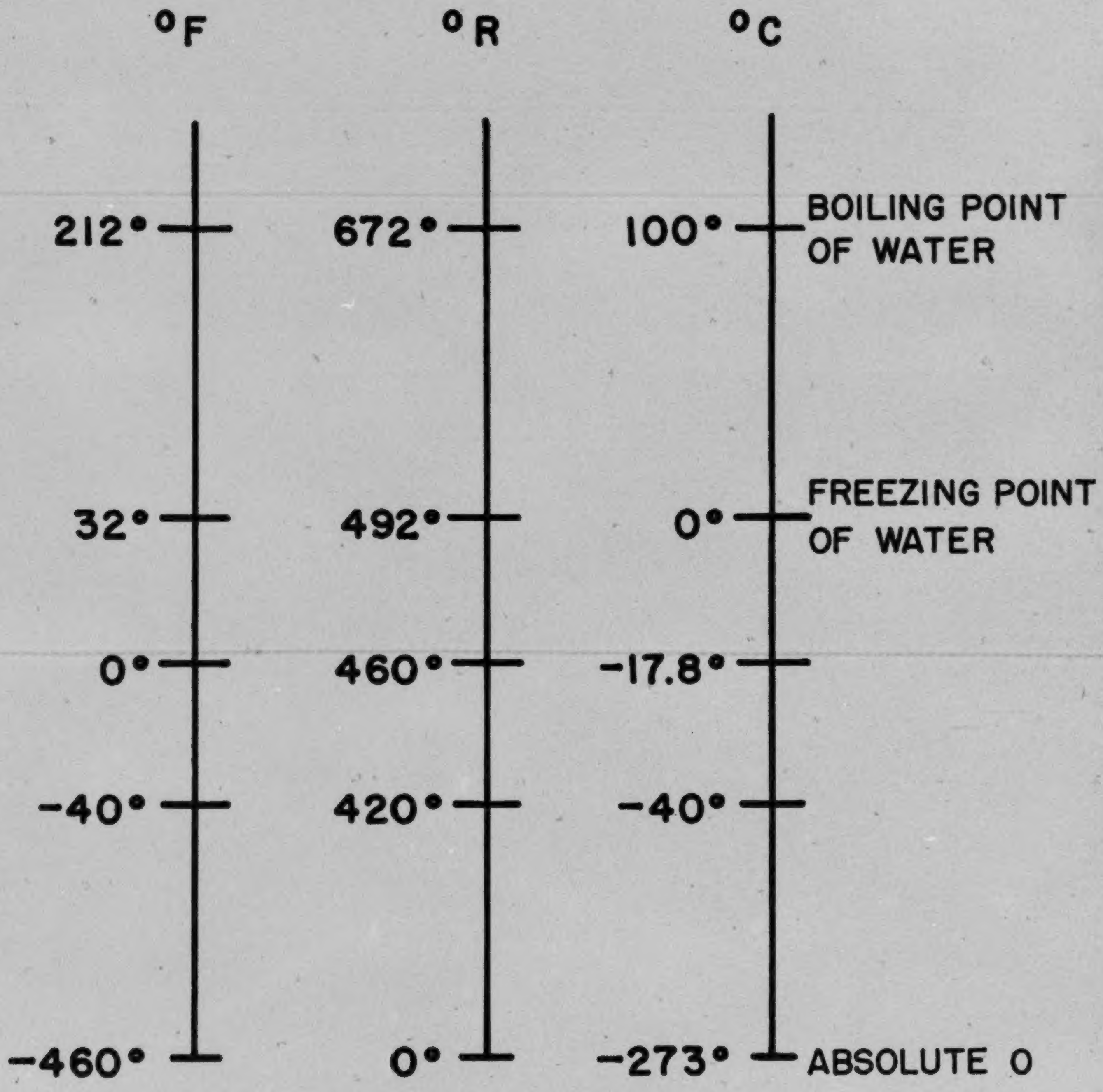
$$\begin{aligned}\text{Ft. lbs.} &= \text{Btu} \times 778\\ &= 1200 \times 778\\ &= 933600 \text{ Ft. lbs.}\end{aligned}$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment: 1. Convert the following to degrees Fahrenheit, centigrade and Rankine as indicated:

	°C	°F	°R
a.	32°	___	___
b.	___	35°	___
c.	___	___	650°
d.	___	96°	___
e.	45°	___	___
f.	___	20°	___
g.	___	___	720°
h.	40°	___	___
i.	___	250°	___
k.	___	___	550°

2. There are 33,000 ft. lbs./min. in a mechanical horsepower. How many Btu's would this be equivalent to?
3. One boiler horsepower is equal to 34.5 pounds of water evaporated per hour from and at 212°F. The latent heat of evaporation is 970.3 Btu's per pound. How many foot-pounds would there be in a boiler horsepower.

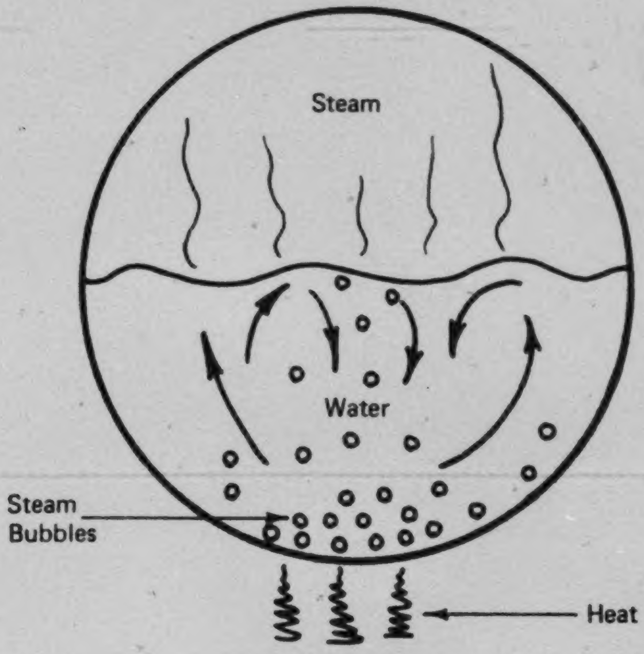

°F
°R
°C
212°
672°
100°
BOILING POINT OF WATER
32°
492°
0°
FREEZING POINT OF WATER
0°
460°
-17.8°
-40°
420°
-40°
-460°
0°
-273°
ABSOLUTE 0

2-C-1-MI

Objectives:

1. Be able to describe how steam forms in firetube and watertube boilers.
2. Be able to describe how the steam and water circulates in firetube and watertube boilers.

Information: In order to understand what is happening inside a boiler drum when heat is applied, let's look at a simple drum:



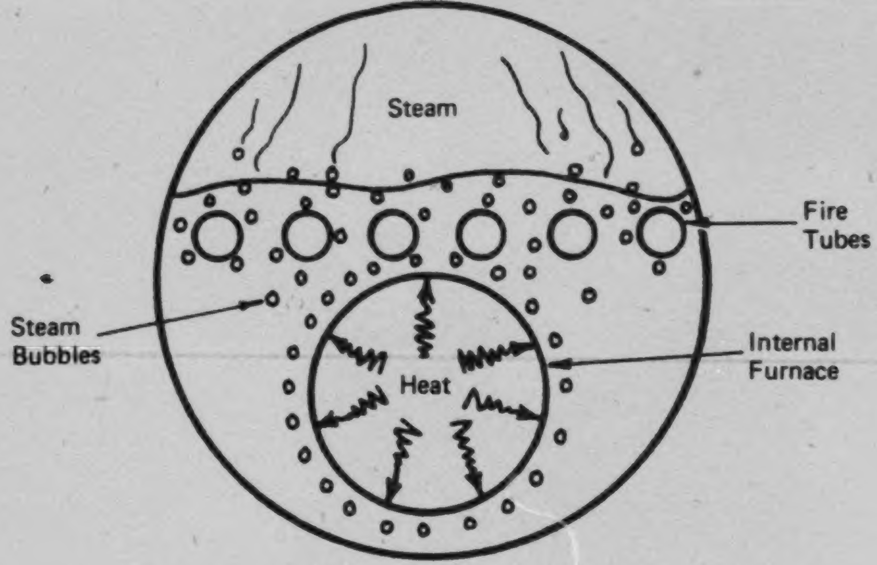
2-C-2-1

The sketch shows that steam bubbles form at the heated surface. The heated water and bubbles are displaced by the colder water and circulation is established.

The cycle is as follows:

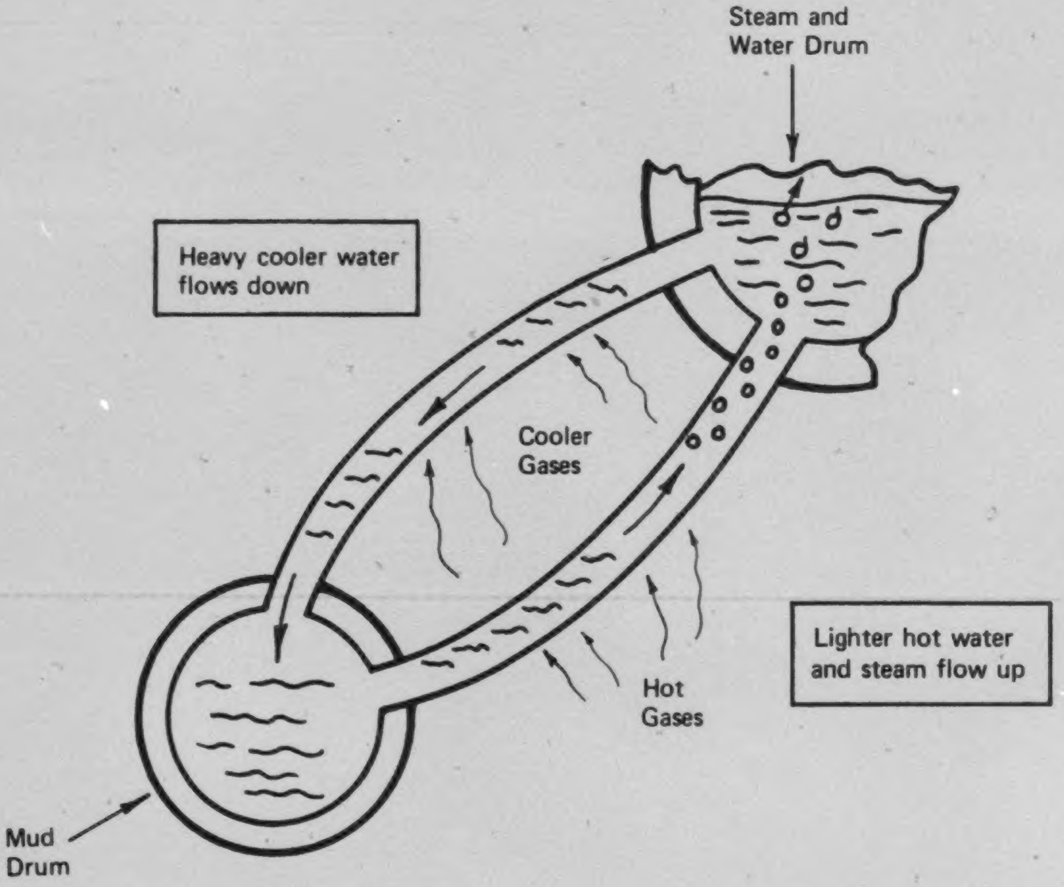
1. Flow of water to heated areas.
2. Flow of steam and heated water to upper areas
3. Release of steam.

It should be quite clear that by adding more heating surface we should get more rapid circulation resulting in a quicker steaming boiler.


Steam
Fire Tubes
Steam Bubbles
Internal Furnace
Heat

2-C-2-2

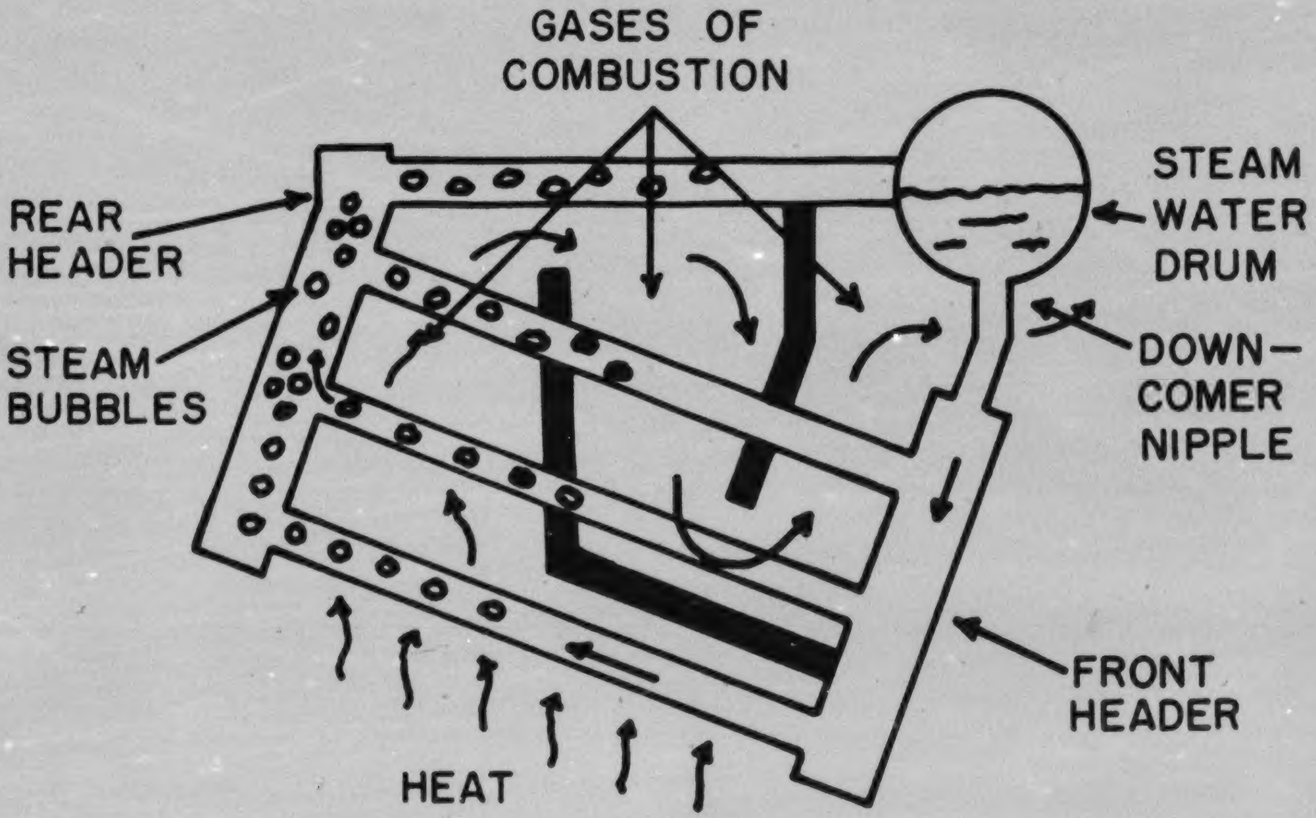
Heating surface is defined as any part of the boiler that has water on one side and fire or gases of combustion on the other side.


Steam and Water Drum
Heavy cooler water flows down
Cooler Gases
Lighter hot water and steam flow up
Hot Gases
Mud Drum

SIMPLE WATER-TUBE CIRCUIT

2-C-2-3

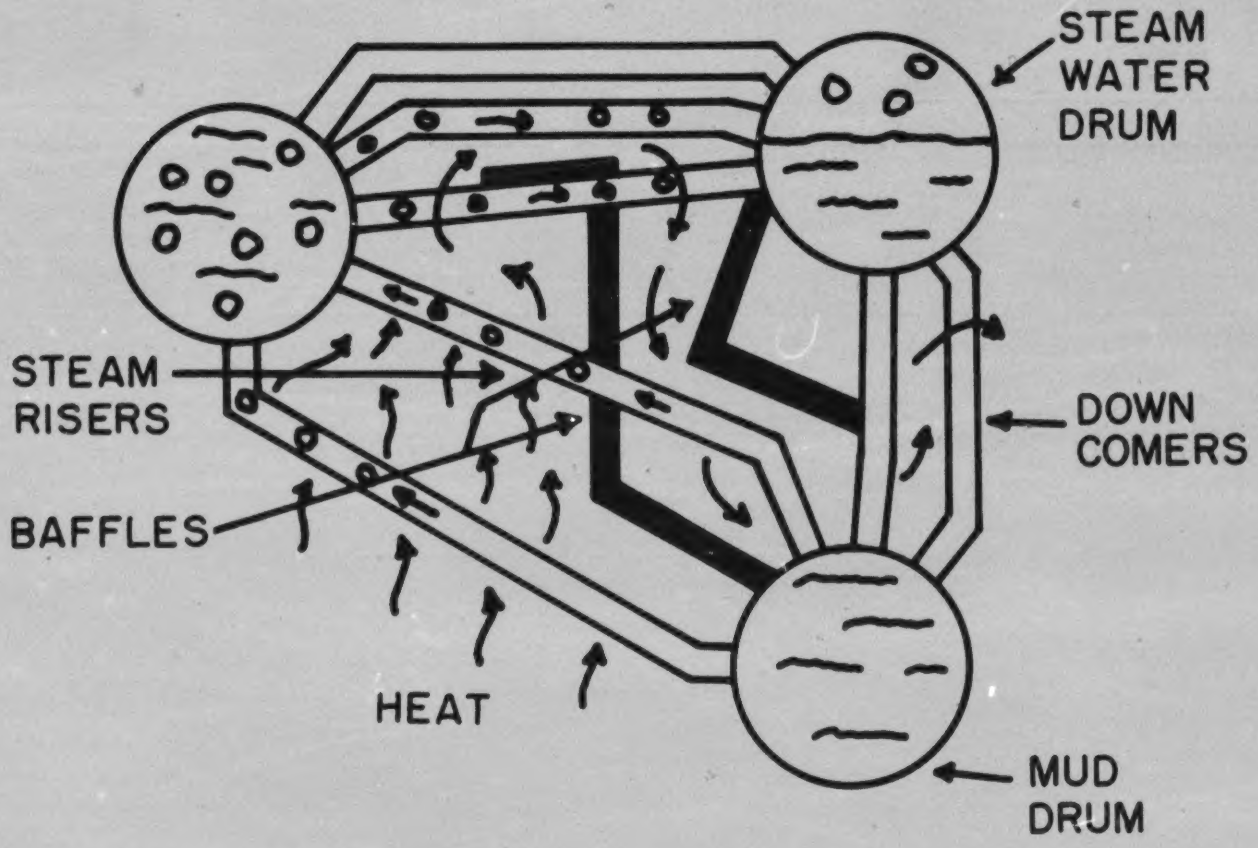
In a simple water tube circuit, the steam forms in the heated tube. The steam and water mixture weigh less than the unheated water coming down. It should be quite clear how the circulation is established. Naturally a higher steaming rate results in faster circulation.


GASES OF COMBUSTION
REAR HEADER
STEAM BUBBLES
STEAM WATER DRUM
DOWN-COMER NIPPLE
FRONT HEADER
HEAT

STRAIGHT TUBE CIRCUIT

2-C-2-4

This sketch is very much like a B & W boiler which you will learn more about in other units. The gases must make three passes before leaving and both front and rear headers are heated. Where are most of the steam bubbles forming? Why?


STEAM WATER DRUM
STEAM RISERS
DOWN COMERS
BAFFLES
HEAT
MUD DRUM

BENT TUBE BOILER CIRCUIT

42

2-C-2-5

3

Circulation becomes more complex in a bent tube multi-drum boiler. Notice that the rear tube bank acts as downcomer to the mud drum, and that most of the steaming occurs in the inclined tube banks. This is again a 3-pass boiler. The steam and water mixture enters the steam drum both above and below the water's surface.

Reference: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Describe how steam forms in a simple drum.
2. Is there any advantage in adding internal heat?
3. Describe the circulation in:
    a. Simple water tube circuit
    b. Straight tube circuit
    c. Bent tube circuit
4. Where does most of the steam bubbles form in a straight tube and bent tube circuit? Why?
5. Sketch a straight tube boiler circuit.
6. Sketch a bent tube circuit.

Objective: Be able to describe the properties of saturated and superheated steam.

Information: Saturated steam is a vapor at a temperature that corresponds with its pressure. Any removal of heat from the steam vapor would cause a portion of the steam to condense back into the liquid state. The temperature of the saturated steam is the same as the water it is in contact with. That temperature is dependent upon the pressure inside the container. For example, water boils at 212°F at zero p.s.i., but water boils at 337°F at 100 p.s.i.

In both cases, the steam and the water are at the same temperature (212°F in the first example and 337°F in the second example.) These examples show that the temperature needed for saturated steam increases as the pressure increases.

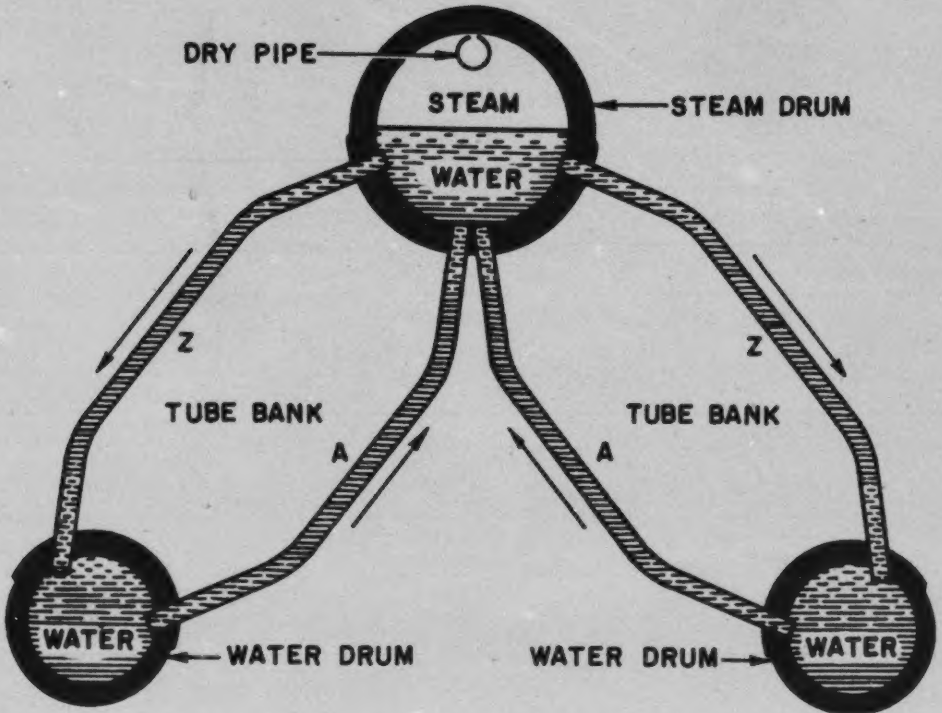
Steam may be either wet or dry when it is generated. If all steam that leaves the water is completely evaporated, the steam is *dry*. If there are water droplets in the steam, it is *wet saturated.*

Quality is a term showing the amount of water in steam. The quality of saturated steam is expressed as a percent of the total steam evaporated. If steam leaving a boiler had a quality of 98%, it is 98% evaporated (or contains 2% water).

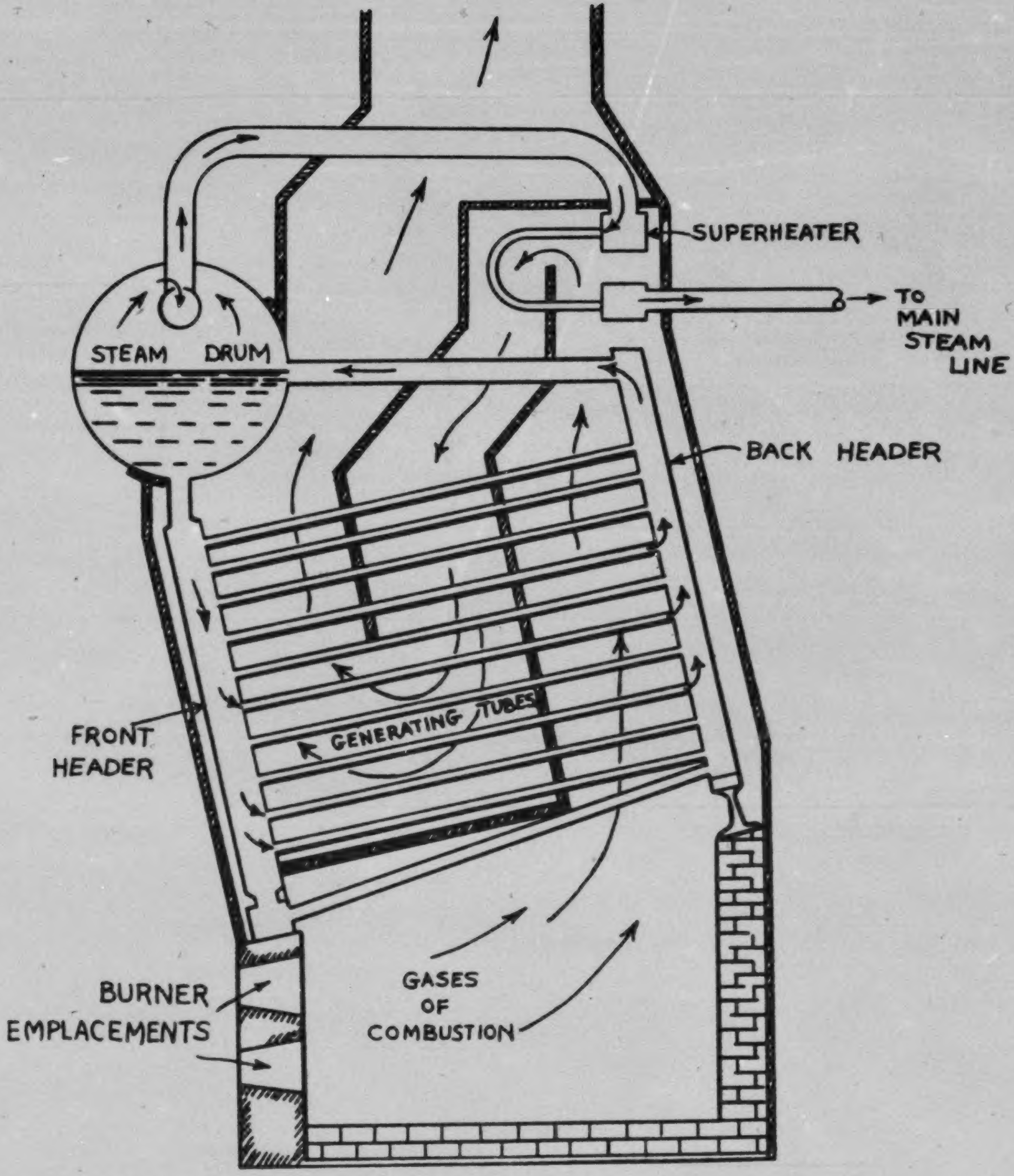
Dry saturated steam has a Btu content of approximately 1200 Btu per pound. (The steam tables used to find the number of Btu will be explained in a later lesson.)

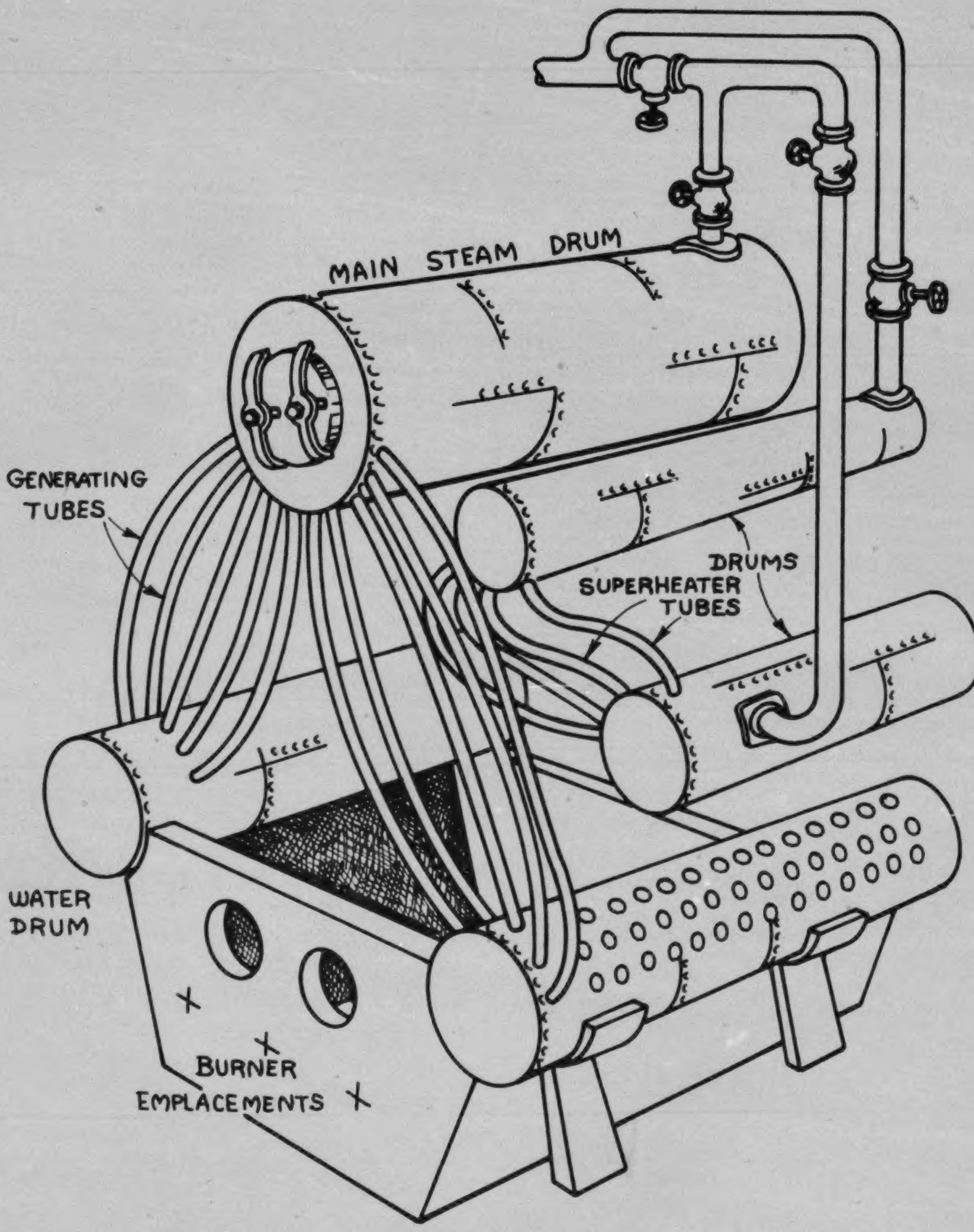
Superheated steam is steam at a temperature higher than its corresponding pressure (the pressure at which both the water and the steam are at the same temperature.) Heat has been added to the steam after it has been removed from its liquid. Saturated steam is superheated by passing through a heater after the steam has been removed from its liquid. The degree of superheat would depend on the difference in temperature of the saturated steam compared to the superheated state of the same steam.

For example, saturated steam at 100 p.s.i. is at a temperature of 337° F. If it were heated to 500°F, it would have a superheat of 500°F - 337°F, or 163°Sh (superheat).


DRY PIPE
STEAM
STEAM DRUM
WATER
Z
Z
TUBE BANK
TUBE BANK
A
A
WATER
WATER DRUM
WATER DRUM
WATER

2-C-3-1


SUPERHEATER
TO MAIN STEAM LINE
STEAM DRUM
BACK HEADER
FRONT HEADER
GENERATING TUBES
BURNER EMPLACEMENTS
GASES OF COMBUSTION


MAIN STEAM DRUM
GENERATING TUBES
DRUMS
SUPERHEATER TUBES
WATER DRUM
BURNER EMPLACEMENTS

The total heat per pound of superheated steam is the heat in the dry saturated steam plus the heat added to superheat the steam. The total heat per pound of superheated steam is in the tables for superheated steam, which will be explained in a later lesson.

References: *Steam Plant Operation*
Elementary Steam Power Engineering.

Assignment:
1. Define saturated steam.
2. Define superheated steam.
3. What is meant by the term, "Quality of Steam"?
4. Where could you find the pressure-temperature relationship of saturated steam?
5. How would you find the total heat in a pound of saturated steam?
6. How would you find the total heat in a pound of superheated steam?

Gas Laws: Review — Assignment 2-D-1

Objectives:

1. Be able to apply Charles' Laws.
2. Be able to apply Boyle's Law.

Information: The relationship between the volume, temperature, and pressure of gases follows definite laws. Charles' First Law is for a constant pressure process. It states: If you heat a gas at a constant pressure, the volume will increase as the temperature increases. A decrease in temperature will have the opposite effect. You would get a decrease in volume. This can be written as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where V_1 and T_1 are the volume and temperature of the gas before heating or cooling, and V_2 and T_2 are for after heating and cooling.

Charles' Second Law is for a constant volume process, and states: If you heat a gas at a constant volume, the pressure will increase as the temperature increases. A decrease in temperature would have the opposite effect; you would get a decrease in pressure. This can be written as:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

where P_1 and T_1 are the pressure and temperature of the gas before heating or cooling and P_2 and T_2 are after heating or cooling.

In the above discussion, temperature is measured in (Rankine) absolute degrees. Volume is in cubic feet and pressure is in pounds per square inch absolute.

You now know that there is a relationship between the volume, temperature, and pressure of gases and that gases do follow definite laws. Boyle's Law is for a constant temperature process, and states: For each change of pressure, there is an inverse change of the volume. This is the same as saying: When the pressure goes up, the volume goes down, or when the pressure goes down, the volume goes up (increases). This can be written as:

$$P_1 = \frac{1}{V_1} \qquad \text{or} \quad P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{1}{V_2}$$

where P_1 and V_1 is the condition before change, and P_2 and V_2 is the condition after change. Temperature is constant. In the above discussion, pressure is measured in pounds per square inch absolute. Volume is in cubic feet.

The combining of Charles' and Boyle's Laws gives the basis for the General Gas Law. The law states that the product of the pressure and the volume divided by the temperature, is equal to the product of the pressure and the volume divided by the temperature. This is the same as saying:

$$\begin{array}{cc} \frac{P_1V_1}{T_1} & \frac{P_2V_2}{T_2} \\ \text{Before change} & \text{After change} \end{array}$$

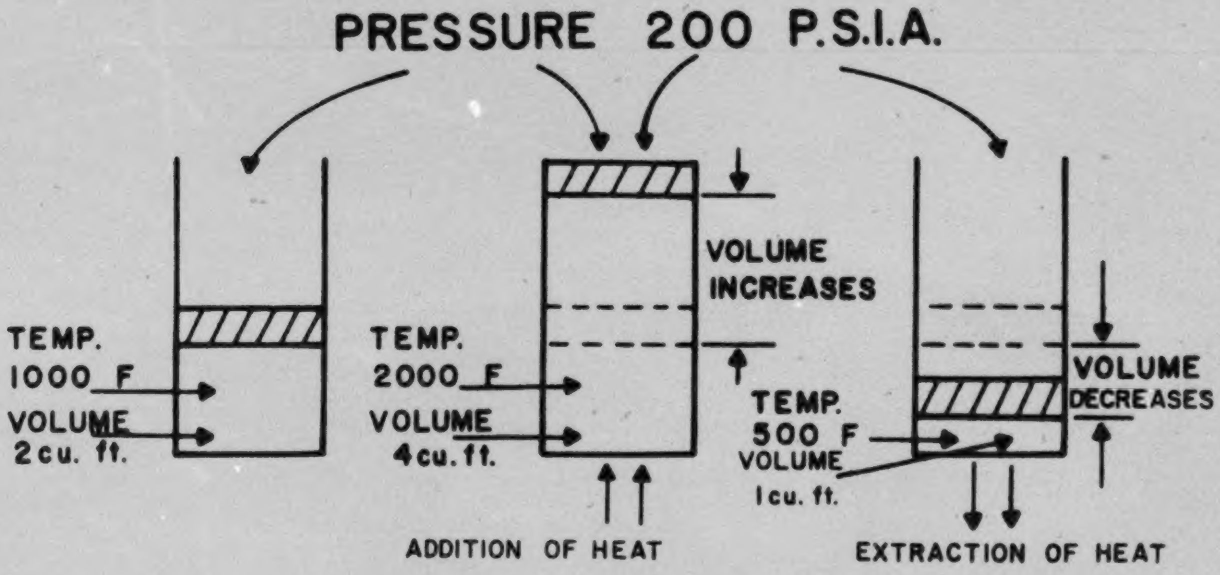
The unit used will be:

Pressure – p.s.i.a. (pounds per square feet absolute).
Volume – cu. ft. (cubic feet).
Temperature – °R (degrees Rankine).

References: *Steam Plant Operation*
Elementary Steam Power Engeneering

Assignment:

1. Explain Charles' First Law and show an example of how it can be used.
2. Explain Charles' Second Law and show an example of how it can be used.
3. State Boyle's Law.
4. What is the equation derived from Boyle's Law?
5. What is the General Gas Law?
6. How was it derived?
7. How is it used?

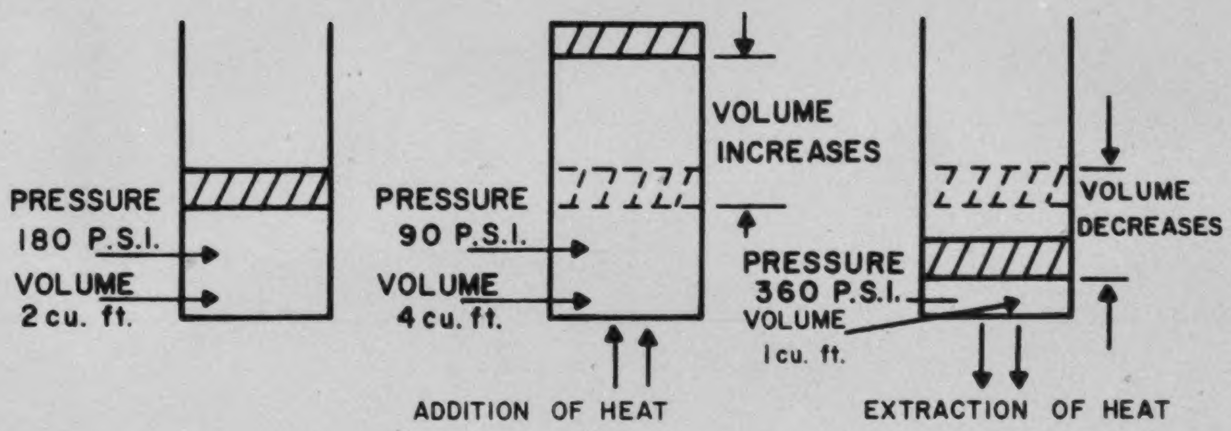

PRESSURE 200 P.S.I.A.
TEMP. 1000 F
VOLUME 2 cu. ft.
TEMP. 2000 F
VOLUME 4 cu. ft.
VOLUME INCREASES
ADDITION OF HEAT
TEMP. 500 F
VOLUME 1 cu. ft.
VOLUME DECREASES
EXTRACTION OF HEAT

CONSTANT PRESSURE:

1. ADDITION OF HEAT-TEMPERATURE AND VOLUME INCREASES.
2. EXTRACTION OF HEAT-TEMPERATURE AND VOLUME DECREASES.

2-D-1-1

TEMPERATURE


PRESSURE
180 P.S.I.
VOLUME
2 cu. ft.
PRESSURE
90 P.S.I.
VOLUME
4 cu. ft.
VOLUME
INCREASES
ADDITION OF HEAT
PRESSURE
360 P.S.I.
VOLUME
1 cu. ft.
VOLUME
DECREASES
EXTRACTION OF HEAT

CONSTANT TEMPERATURE:

1. ADDITION OF HEAT-VOLUME INCREASES AND PRESSURE DECREASES.

2. EXTRACTION OF HEAT-PRESSURE INCREASES VOLUME DECREASES.

2-D-1-2

Solving Pressure-Temperature-Volume Problems — Assignment 2-D-1-M1

Objective: Be able to solve pressure-temperature-volume problems using the General Gas Law.

Information: From your previous lesson you know that if the pressure on a gas is kept constant, its volume will change in direct proportion to its temperature. This can be expressed by using the following formula:

$$\frac{\text{Volume } (V_1)}{\text{Temperature } (T_1)} = \frac{\text{Volume } (V_2)}{\text{Temperature } (T_2)}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

For example, what would be the volume of 10 cubic feet of gas at 90°F if it was heated to 200°F?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad V_2 = \frac{V_1 \times T_2}{T_1}$$

Note: (Degrees Rankine)

$$V_2 = \frac{10 \times (200 + 460)}{90 + 460}$$

$$V_2 = \frac{10 \times 660}{550}$$

$$V_2 = 12 \text{ Cu. Ft.}$$

Charles' Law also stated that if the volume of a gas was kept constant its pressure would change directly proportional to its temperature, or:

$$\frac{\text{Pressure } (P_1)}{\text{Temperature } (T_1)} = \frac{\text{Pressure } (P_2)}{\text{Temperature } (T_2)}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

For example, find the pressure on a gas tank that has been heated from an initial temperature of 90°F at 100 p.s.i.a. to 200°F

$$\frac{P_1}{T_2} = \frac{P_2}{T_2} \qquad P_2 = \frac{P_1 \times T_2}{T_1}$$

Note: Temperature in Rankine scale; pressure in absolute scale.

$$P_2 = \frac{100 \times (200 + 460)}{90 + 460}$$

$$P_2 = \frac{100 \times 660}{550}$$

$$P_2 = 120 \text{ p.s.i.a.}$$

Boyle's Law states that the volume of a gas will vary inversely with its pressure if the temperature remains constant. That is:

$$P_1 = \frac{1}{V_1} \qquad P_2 = \frac{1}{V_2} \qquad \text{or} \qquad P_1 V_1 = P_2 V_2$$

This formula can be used to solve many pressure-volume problems.

For example, if one cubic foot of air is expanded at constant temperature to 2 cubic feet and the initial pressure was 100 p.s.i.a., what is the final pressure?

$$P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$P_2 = \frac{100 \times 1}{2}$$

$$P_2 = 50 \text{ p.s.i.a.}$$

In the problem above what would the final volume be if the final pressure was 200 p.s.i.a.?

$$P_1 V_1 = P_2 V_2$$

$$V_2 = \frac{P_1 V_1}{P_2}$$

$$V_2 = \frac{100 \times 1}{200}$$

$$V_2 = .5 \text{ cu. ft.}$$

When Charles' and Boyle's Laws are combined you have what is commonly known as the General Gas Law. Charles' Laws were expressed as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

And Boyle's Law states that:

$$P_1 = \frac{1}{V_1} \qquad P_2 = \frac{1}{V_2} \qquad \text{or} \quad P_1 V_1 = P_2 V_2$$

Now by combining we find that:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

This formula can be used to solve many pressure-volume-temperature problems.

For example, from the following data what would be the final gas volume, V_2:

P_1 = 15 p.s.i.a.
V_1 = 1 cu. ft.
T_1 = 70°F
P_2 = 30 p.s.i.a.
V_2 = __________
T_2 = 600°F

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{15 \times 1 \times 1060}{530 \times 30} = 1 \text{ cu. ft.}$$

Transpose for each unknown and substitute values from above.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Solve for P_1 $\quad P_1 = \frac{P_2 V_2 T_1}{V_1 T_2} = \frac{30 \times 1 \times 530}{1 \times 1060} = 15$ p.s.i.a.

Solve for V_1 $\quad V_1 = \frac{P_2 V_2 T_1}{P_1 T_2} = \frac{30 \times 1 \times 530}{15 \times 1060} = 1$ cu. ft.

Solve for T_1 $\quad T_1 = \frac{P_1 V_1 T_2}{P_2 V_2} = \frac{15 \times 1 \times 1060}{30 \times 1} = 530°R$

Solve for P_2 $\quad P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{15 \times 1 \times 1060}{530 \times 1} = 30$ p.s.i.a.

Solve for V_2 $\quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{15 \times 1 \times 1060}{530 \times 30} = 1$ cu. ft.

Solve for T_2 $\quad T_2 = \frac{P_2 V_2 T_1}{P_1 V_1} = \frac{30 \times 1 \times 530}{15 \times 1} = 1060°R$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. A gas whose initial temperature is 60°F and has a volume of 5 cu. ft. is heated at a constant pressure to 580°F. What is its final volume?
2. A gas having an initial temperature of 80°F is cooled at a constant pressure until its temperature is 40°F. If the initial volume of the gas is 8 cu. ft., what is its final volume?
3. A gas has an initial temperature of 80°F and a pressure of 30 p.s.i. If the gas is heated until the final pressure is 50 p.s.i., what is the final temperature in °F? Volume is kept constant.

4. A gas tank has a pressure of 15 p.s.i. and a temperature of 50°F. At what temperature would the pressure double?
5. When 5 pounds of air is expanded at a constant temperature from an initial volume of 5 cu. ft. to a final volume of 10 cu. ft. and the initial pressure of the air is 20 p.s.i.a., what is the final pressure?
6. When 4 cu. ft. of gas is allowed to expand at a constant temperature from an initial pressure of 8 p.s.i.a. to a final pressure of 2 p.s.i.a., what is the final volume of the gas?
7. Find the initial pressure or volume of the following:

a. P_1 = ______
V_1 = 15 cu. ft.
P_2 = 45 p.s.i.a.
V_2 = 60 cu. ft.

b. P_1 = 110 p.s.i.a.
V_1 = ______
P_2 = 55 p.s.i.a.
V_2 = 500 cu. ft.

c. P_1 = ______
V_1 = 30 ft.
P_2 = 75 p.s.i.a.
V_2 = 90 cu. ft.

d. P_1 = 80 p.s.i.a.
V_1 = ______
P_2 = 40 p.s.i.a.
V_2 = 250 cu. ft.

8. Find the final pressure or volume of the following:

a. P_1 = 180 p.s.i.a.
V_1 = 30 cu. ft.
P_2 = ______
V_2 = 120 cu. ft.

b. P_1 = 220 p.s.i.a.
V_1 = 250 cu. ft.
P_2 ______
V_2 = 110 cu. ft.

c. P_1 = 225 p.s.i.a.
V_1 = 60 cu. ft.
P_2 = 150 p.s.i.a.
V_2 = ______

P_1 = 160 p.s.i.a.
V_1 = 125 cu. ft.
P_2 = 80 p.s.i.a.
V_2 = ______

9. Solve for the unknown values:

	P_1	V_1	T_1	P_2	V_2	T_2
a.	100	5	600	250	10	___
b.	50	10	650	150	___	850
c.	30	25	700	___	15	1400
d.	250	10	___	100	5	600
e.	150	___	1300	50	10	650
f.	___	15	1400	30	25	700

Note: all above values are in absolute – p.s.i.a., °Rankine, and cu. ft.

10. How many times will a gas expand in a turbine if the initial temperature is 1500°R, the pressure is 500 p.s.i.a., and the volume is 100 cu. ft., and at the end the pressure is 1 p.s.i.a. and the temperature is 500°R?

Hint: How many times will the volume change?

Objective: Be able to describe the relationship that exists between steam pressure and its temperature.

Information: Steam is water in a semi-gaseous condition. It is a vapor rather than a gas, and does not follow the laws for gasses. The change from water to steam takes place at a temperature that is dependent on the pressure within the vessel. At atmospheric pressure (zero p.s.i.), water will boil at 212°F. This means that the water is releasing steam at 212°F while the water also is at 212°F. When the pressure is increased to 100 p.s.i. the water will now boil at 337°F, and the steam will also be at 337°F.

The boiling point of water increases with additional increases in pressure until the critical pressure-temperature point is reached. The critical pressure is 3206 p.s.i.a., and its corresponding temperature is 705°F. When this pressure-temperature point is reached, water will not remain in the liquid state. This applies to saturated steam generated in a pressure vessel.

The boiling point of water at various pressures can be found in the Dry Saturated Steam tables. The pressures are in pounds per square inch absolute and the temperature is in degrees Fahrenheit. When steam is removed from its liquid and heated to a higher temperature, we say it is superheated, or that it has a given number of degrees of superheat. The number of degrees is the difference between the saturated temperature at that pressure and the actual steam temperature.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:
1. Define steam.
2. What is meant by the term "boiling point"?
3. Why does the boiling point of water change in a boiler?
4. Does the water in all boilers boil at the same temperature? Explain.
5. What is meant by the critical point in steam boilers? Explain in detail.
6. What is the difference between saturated and superheated steam?

Objective: Be able to plot a pressure temperature steam chart.

Information: From our previous lesson, you know that there is a relationship between the boiling point of water and the pressure being exerted on the water.

This pressure-temperature relationship can be expressed graphically by using pressure as the "X" axis and temperature as the "Y" axis. All values can be taken from the dry saturated steam tables. A graph for superheated steam showing pressure versus temperature can also be constructed. The degree of superheat has to be known and added to the dry saturated temperature.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Complete a pressure-temperature graph of dry saturated steam starting at 50 p.s.i.a. with 50 p.s.i. divisions and ending at 900 p.s.i.a.
2. Complete a pressure-temperature graph of 200° superheated steam starting at 50 p.s.i.a. with 50 p.s.i. divisions and ending at 900 p.s.i.a.

Note: Use the dry saturated steamtables for the above problems.

Objective: Be able to use the dry saturated steam tables.

Information: When you are driving in or to a strange location, you look for street signs. You may also use a road map. Steam tables are road maps and street signs for stationary engineers. The engineer should be familiar with them and know how to use them. But before this can be done, we must first review some terminology.

Gauge pressure: The pressure recorded on a steam gauge.

Absolute pressure: Gauge pressure + atmospheric pressure.

Latent heat: Hidden heat. It changes the state of a substance, but not its temperature.

Latent heat of fusion: Changes ice from 32°F to water at 32°F (requires 144 btu per pound).

Sensible heat: Changes substance's temperature, but not its state (water 32°F to steam 212°F; requires 180 btu per pound).

Latent heat of evaporation: Changes water at 212°F to steam at 212°F (takes 970.4 btu per pound).

Enthalpy: Total heat of steam; the sum of sensible and latent heat.

Note: Sensible heat becomes the enthalpy of the liquid, latent heat becomes enthalpy of evaporation, and total heat becomes enthalpy of steam.

A study of the steam tables will show that steam has a corresponding temperature and pressure and as the pressure increases the:

1. boiling point increases.
2. sensible heat increases
3. latent heat decreases
4. total heat increases slowly until the pressure is approximately 450 p.s.i.a; then decreases slowly until pressure approaches the critical pressure of 3200 p.s.i.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment: 1. Define:

   a. Gage pressure.
   b. Absolute pressure
   c. Enthalpy
   d. Latent heat of evaporation
   e. Sensible heat

2. How may Btu. are necessary to raise the temperature of 1 pound of water from 32°F to 212°F?
3. How many Btu. are necessary to change water at 212°F to steam at 212°F?
4. What will a study of the steam tables show?
5. As the steam pressure increases, what happens to the latent heat of evaporation?
6. What is the critical pressure of steam?
7. Using steam tables in *Steam Plant Operation*, make 3 graphs showing following:

   a. Temperature of steam
   b. Enthalpy of saturated liquid
   c. Enthalpy of evaporation

   and using pressures as follows:

   a. 20 p.s.i.g.
   b. 65 p.s.i.g.
   c. 70 p.s.i.g.
   d. 80 p.s.i.g.
   e. 100 p.s.i.a.
   f. 120 p.s.i.a.

Objective: Be able to solve problems using the steam tables.

Information: When looking for information in the Dry Saturated Steam Tables, you will sometime find that the information you seek is given directly. At other times, it will be necessary to interpolate between given values.

Example: When the steam pressure is 24 p.s.i.a. find the:

a. Enthalpy of saturated liquid
b. Latent heat of evaporation
c. Enthalpy of saturated vapor
d. Saturated temperature of steam

You will note from your steam tables that 24 p.s.i.a. is not recorded, but 20 p.s.i.a. and 25 p.s.i.a. are recorded.

To interpolate and find the enthalpy of saturated liquid, proceed as follows:

$$\begin{array}{ccc} \textbf{Pressure} & & \textbf{Enthalpy} \\ \left.\begin{matrix} 4\left[\begin{matrix}20\\24\end{matrix}\right.\\ 25\end{matrix}\right]5 & \Rightarrow & \left.\begin{matrix}196.16\\205.968\\208.42\end{matrix}\right]12.26 \end{array}$$

$$24 - 20 = \frac{4}{5} \qquad 208.42 - 196.16 = 12.26$$
$$25 - 20 = 5$$

Multiply $\frac{4}{5} \times 12.26 = 9.808$

Then add $196.16 + 9.808 = 205.968$

The enthalpy of saturated liquid for steam at 24 p.s.i.a. is 205.968 Btu per pound.

Next, to find the latent heat of evaporation of steam at 24 p.s.i.a.

	Pressure			Latent Heat of Evaporation	
	20			960.1	
4	24	5	➜	953.7	8.0
	25			952.1	

Multiply $\frac{4}{5} \times 8 = 6.4$

Since the latent heat of evaporation decreases as the pressure increases, subtract 6.4 from 960.1 which is the latent heat of evaporation at 24 p.s.i.a.

960.1 - 6.4 = 953.7 Btu/lb.

Then find the enthalpy of dry saturated steam at 24 p.s.i.a.

	Pressure			Enthalpy	
	20			1156.3	
4	24	5	➜	1159.74	4.3
	25			1160.6	

Multiply $\frac{4}{5} \times 4.3 = 3.44$

Then add 1156.3 + 3.44 = 1159.74 Btu/lb. which is the enthalpy of steam at 24 p.s.i.a.

To find the dry saturated steam temperature at 24 p.s.i.a.

	Pressure			Dry Saturated Steam	
	20			227.96	
4	24	5	➜	237.648	12.11
	25			240.07	

Multiply $\frac{4}{5} \times 12.11 = 9.688$

Add 227.96 + 9.688 = 237.648°F which is the temperature of dry saturated steam at 24 p.s.i.a.

References: *Steam Plant Operation*
Elememtary Steam Power Engineering

Assignment: 1. Find:

a. Enthalpy of saturated liquid
b. Latent heat of evaporation
c. Enthalpy of saturated vapor
d. Saturated temperature of steam

for each of the following pressures which are given in p.s.i.a.

1. 18
2. 22
3. 45
4. 32
5. 113
6. 134,
7. 153
8. 196
9. 223
10. 264

Do all work and then put all answers on separate paper as indicated below:

1 a.
b.
c.
d.

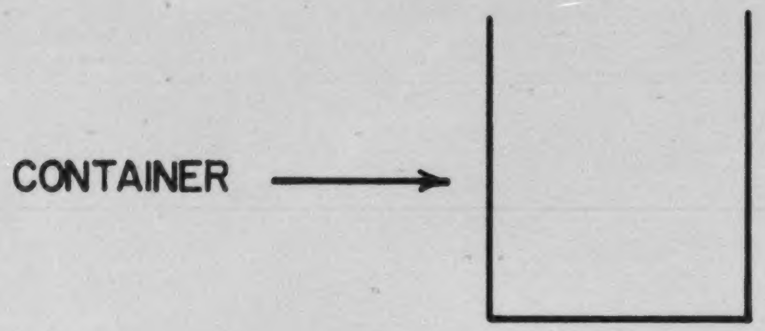
2 a.
b.
c.
d.

3 a.
b.
c.
d. etc...

Objective: Be able to describe how the firetube boiler was developed.

Information: In order to produce steam we need three things:

container
water
heat



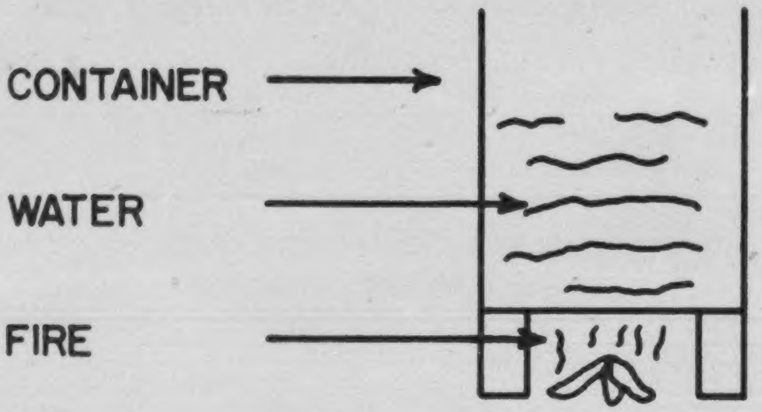
3-A-1-1

The container will serve two purposes. It will hold the water, and it will provide a means of transferring the heat to the water to make steam.

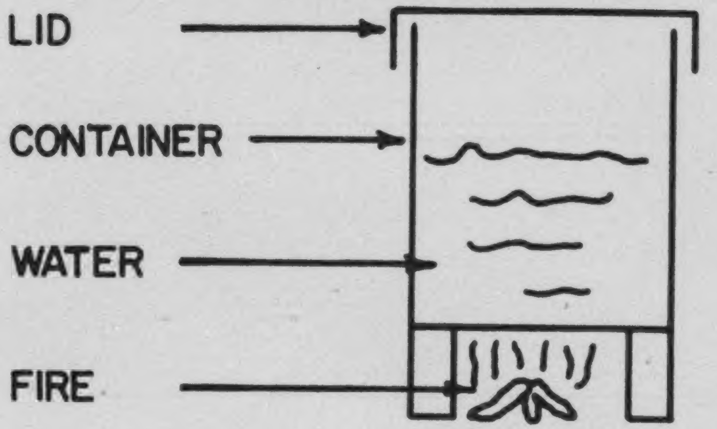
Water is the medium we use to make the steam because it is plentiful and cheap. We could use mercury, or almost any other liquid.

Heat will produce the necessary physical change we are trying to bring about.

Now, we will take our container, fill it half-full of water, and build a fire under it. If we added a top to our container, we would have a simple boiler.



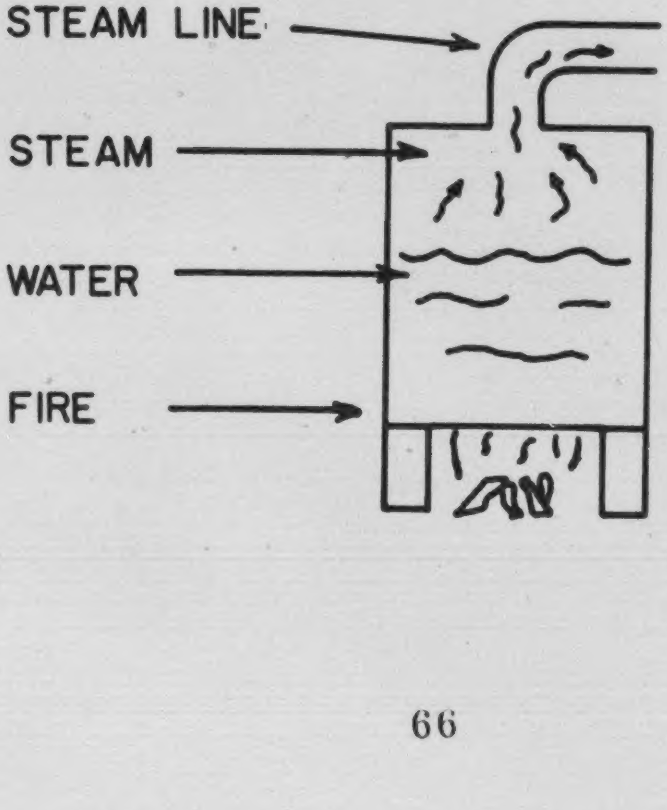
3-A-1-2


LID
CONTAINER
WATER
FIRE

3-A-1-3

When the fire heats the water to 212°F, the water will begin to boil. If more heat is added, the water will change its state and turn into steam. In order to use this steam to do work, we must capture it and lead it to its working station.

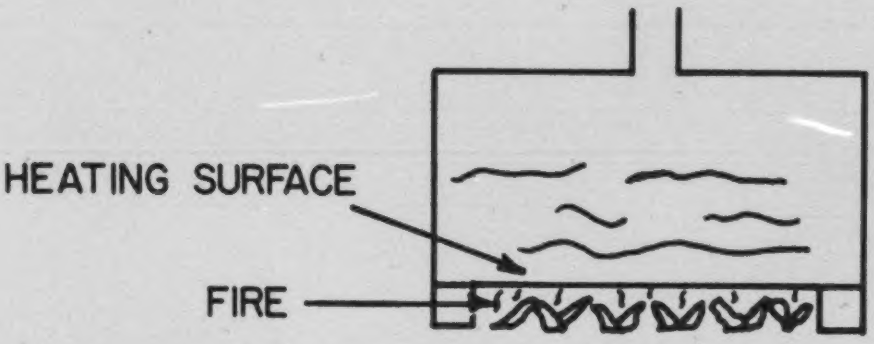
But first we will have to make a few changes. We will put a top on our container, and lead a pipe out so that the steam will flow up through our pipe as it gathers in the top of our container. We can now lead the steam to where it is needed.


STEAM LINE
STEAM
WATER
FIRE

3-A-1-4

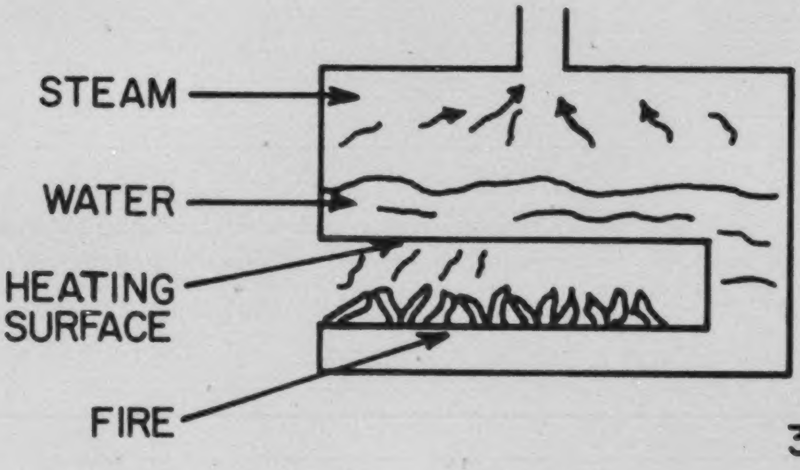
Now, everything would be fine and dandy with such a hook-up except for a factor that always creeps into all pictures –*Money*. We must not waste money making steam so, we must make a more efficient boiler, one that will produce more steam without using more fuel. Now, we start to think, "How can we get more heat from the same amount of fuel?"

Well, one way would be to give the heat a larger surface to work on. By increasing our heating surface, we put more water closer to the heat, so we lay our boiler on its side.



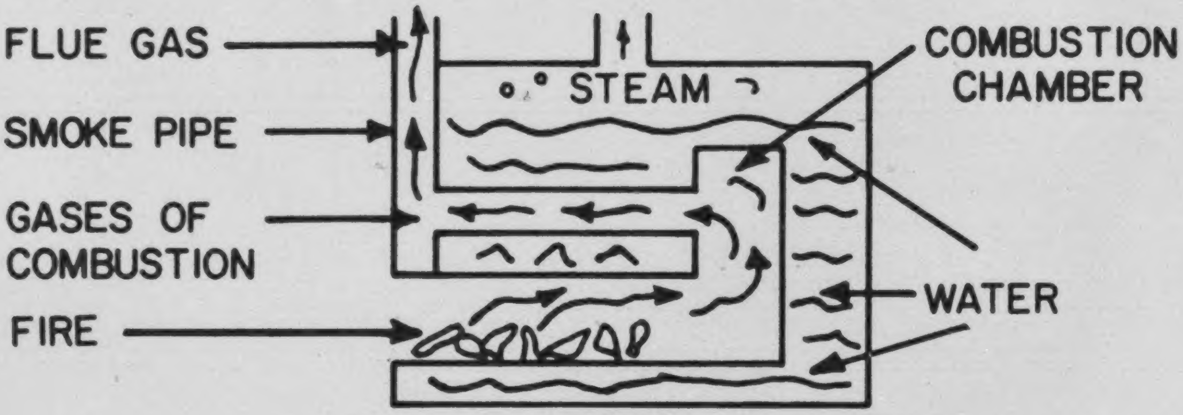
3-A-1-5

This helps, but we should be able to do better. Why not put the fire inside the water? That's what we shall do.



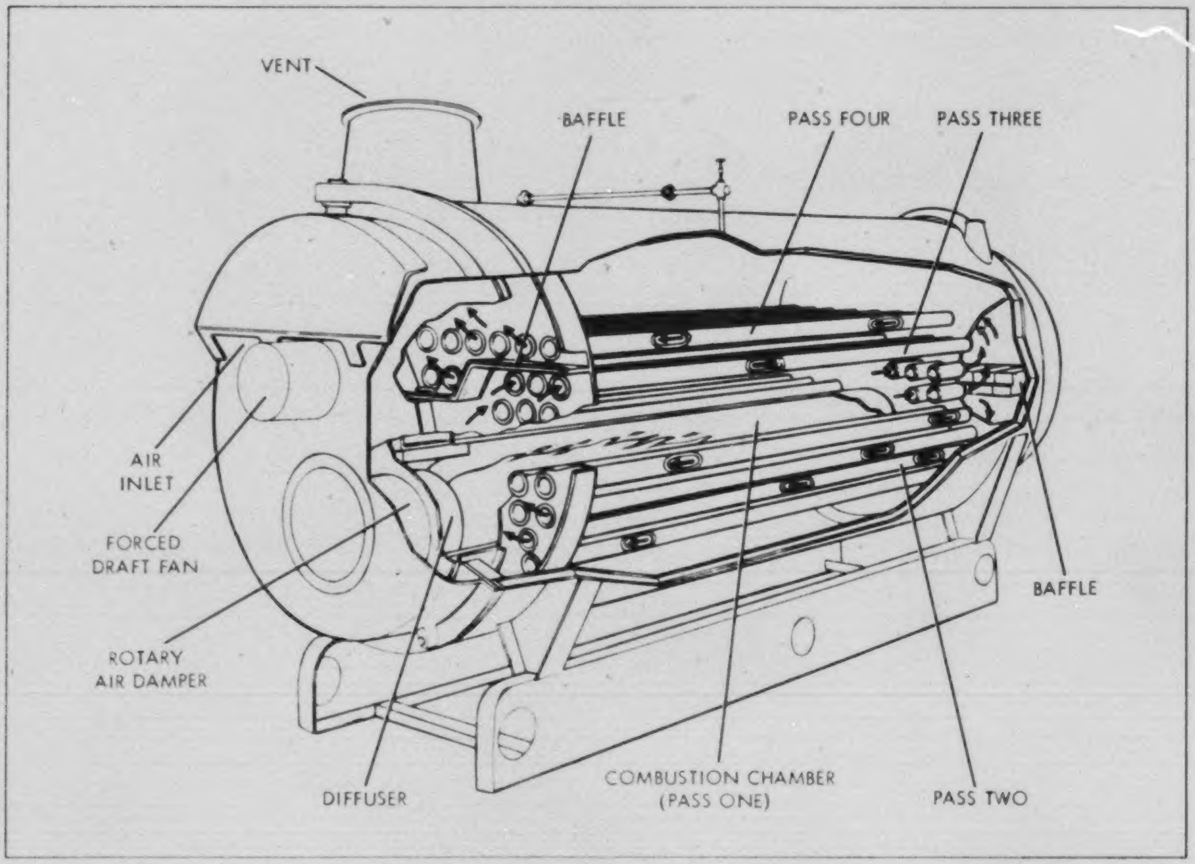
3-A-1-6

Again, there is improvement. We find that the fire would burn better if it had more air and a larger place to complete its burning, so we add a combustion chamber.


FLUE GAS
SMOKE PIPE
GASES OF COMBUSTION
FIRE
STEAM
COMBUSTION CHAMBER
WATER

3-A-1-7

This has indeed helped things along. But, again the cry, *Money, Money, Money!* Cut the fuel bill. Again, we start to look for something a little better. More heating surface is the answer, so we again increase our heating surface. Our final sketch is the Scotch marine boiler, and chances are this is how it was born.


VENT
BAFFLE
PASS FOUR
PASS THREE
AIR INLET
FORCED DRAFT FAN
ROTARY AIR DAMPER
BAFFLE
DIFFUSER
COMBUSTION CHAMBER (PASS ONE)
PASS TWO

3-A-1-8

We still have the same three things we started with:

container – with additions
water
heat

The only difference is that we have put as much water as possible next to the hot metal. This means faster circulation of water which will produce steam faster.

Reference: *Steam Plant Operation*

Assignment:

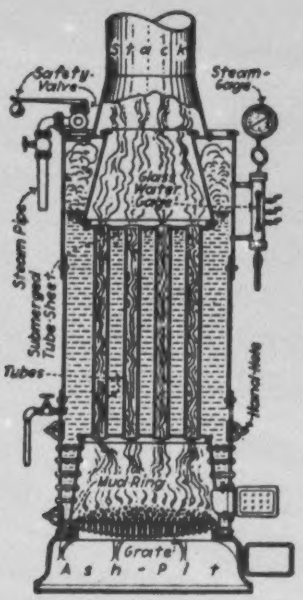
1. What is a boiler?
2. Define a firetube boiler.
3. What is meant by boiler heating surface?
4. Discuss the requirements of a good boiler.
5. List at least 2 boilers that are internally fired and two that are externally fired.

Types and Classification of Firetube Boilers — Assignment 3-A-2

Objective: Be able to identify a firetube boiler as to its type and classification.

Information: In the last lesson we looked into the background of how the Scotch marine boiler came into the world. Just to keep the records straight, the Scotch marine boiler is not the only firetube boiler in the world. Boilers vary in design and horsepower just as cars do. We all know that the Ford is not the only car on the road, althought I'm sure Mr. Ford would like you to believe that it is.

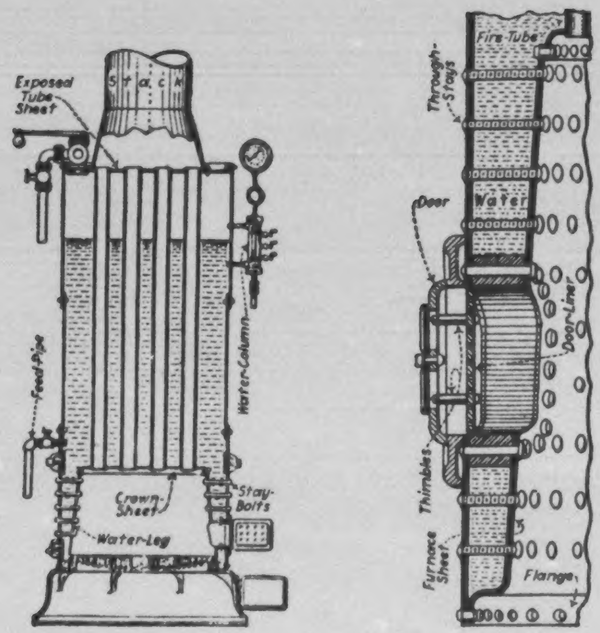
Let's see if we can get to know the different types of firetube boilers. First, we'll look at the vertical firetube boiler. There are two types: the submerged tube type and the exposed tube type. Notice that both these boilers are alike except for the tubes. One has the water level covering the tubes and the other has the upper third of the tubes exposed to the hot gases of combustion.


Stack
Safety-Valve
Steam-Gage
Glass Water Gage
Steam Pipe
Submerged Tube-Sheet
Tubes
Hand-Hole
Mud Ring
Grate
Ash-Pit

Submerged Tube Type
Firetube Boiler

3-A-2-1

Which do you think might have trouble with overheated tubes?

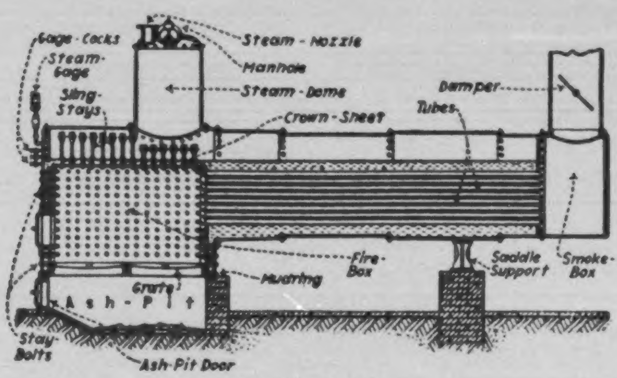

Exposed Tube Sheet
Stack
Feed-Pipe
Water-Column
Crown-Sheet
Stay-Bolts
Water-Leg
Fire-Tube
Through-Stays
Water
Door
Door-Liner
Thimbles
Furnace Sheet
Flange

Exposed Tube Type
Firetube Boiler

3-A-2-2

You can see that the gases of combustion go straight up the tubes to the stack. It's not what we might consider good efficiency. We know that we have to keep the gases of combustion in contact with the heating surface to get the heat to the water.

Now, let's go on to another model: the locomotive type..

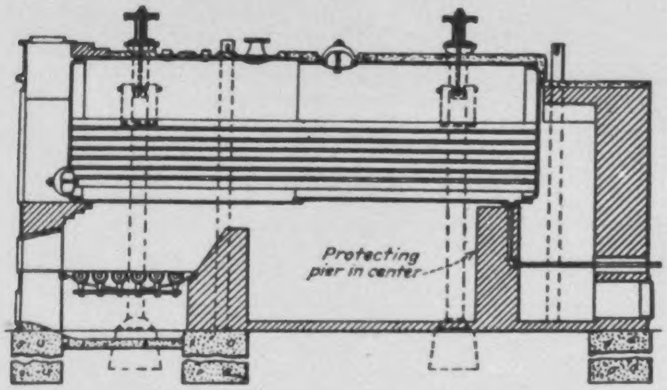

Gage-Cocks
Steam-Gage
Sling-Stays
Steam-Nozzle
Manhole
Steam-Dome
Crown-Sheet
Damper
Tubes
Fire-Box
Mudring
Grate
Ash-Pit
Saddle Support
Smoke-Box
Stay-Bolts
Ash-Pit Door

Locomotive Type Firetube Boiler

3-A-2-3

The name sort of speaks for itself. We find this type on trains and steam tractors. It is a horizontal boiler, and something has been added – a Baffle. The baffle slows up the gases in the furnace. When we keep the gases in contact with the heating surface longer, then more heat is absorbed by the water. Hot gases in the stack are just dollar bills going up the stack.

The next boiler we will look at is the H.R.T. Boiler, meaning the Horizontal Return Tubular.


Protecting pier in center

Horizontal Return Tubular Firetube Boiler

3-A-2-4

It is a boiler that retains the gases a little longer. They have to pass the length of the drum and go through the tubes located inside the drum in order to reach the stack. This boiler will be more efficient than its cousins: the vertical firetube boiler and the locomotive boiler. *It get more miles per gallon of gas.*

In looking back over the boilers, notice that they are all different in looks and design. But, they all have the same basic equipment such as a firebox, fire tubes, safety valve, stop valves, manholes, handholes, gage glass, bottom blow-down valves, pressure gage, etc. A Ford has the same basic equipment as a Buick. They just look different, and one gets more mileage per gallon of gas with a few more bumps. The same thing applies to boilers.

Reference: *Steam Plant Operation*

Assignment:

1. Using the attached chart, identify the school boilers.
2. How many other types of firetube boilers are there?
3. What is meant by a horizontal 4-pass boiler?
4. List the following information about a 4-pass horizontal return tubular boiler:
    a. horsepower range
    b. pressure range
    c. advantages
    d. disadvantages

Objective: Be able to describe the basic construction of a firetube boiler.

Information: The first boilers were used for warming water; they were of Roman and Greek origin. Recovered samples of these were found in the ruins of Pompeii. Branca, an Italian physicist, produced a boiler in 1629, and Savary, produced one in 1698. These were all firetube type boilers.

Early versions of the firetube boiler consisted of riveted shells. The modern firetube boilers are of welded construction. But due to their construction, they are limited in both size and pressure.

Figures 3-A-3-1, 3-A-3-2, 3-A-3-3, and 3-A-3-4 are samples of riveted construction showing the joint efficiencies. Welded joints are considered to be 100% efficient.

The tube sheets of firetube boilers being flat require elaborate methods of staying to prevent bulging..

Figure 3-A-3-5 is a through stay, which is used to hold front and rear tube sheets together. Figure 3-A-3-6 is a stay bolt that holds inner and outer wrapper sheets together. It has a telltale hole 3/16" in diameter extending 1" into the water side of the boiler. If the stay bolt fails, water and steam will leak out, the telltale hole warning the operator so that the stay bolt can be replaced. Figure 3-A-3-7 is a front and side view of a girder stay used to support the crown sheet of a Scotch marine boiler. The crown sheet is the top of the combustion chamber. Figure 3-A-3-8 is a dog stay used to hold manhole and handhole covers in place.

Next time you see a sketch of a firetube boiler locate and identify some of the stays mentioned in this lesson.

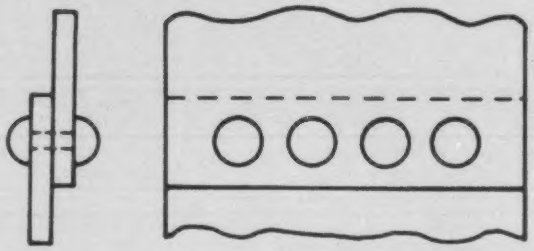
It should be noted here that the Mechanical Inspection Bureau, New Jersey Department of Labor and Industry has juristiction over boiler construction and inspection. In part it states that:

> "All Steam or Hot water boilers used in this State must be constructed and installed in accordance with New Jersey approved standards. This requires that they be constructed and installed according to the A.S.M.E. Code and stamped either New Jersey Standard, New Jersey Approved, A.S.M.E., or National Board."

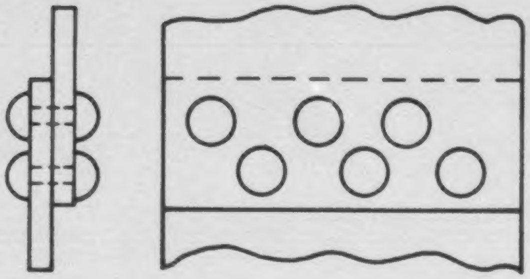
References: *Steam Plant Operation*
Mechanical Inspection Bureau Rules and Regulations

Assignment:

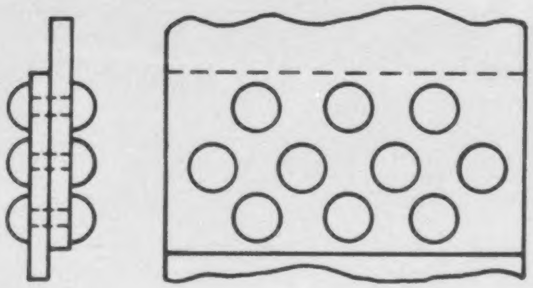
1. What is a longitudinal joint and how is it constructed?
2. What is a circumferential joint and how is it constructed?
3. How is expansion and contraction taken care of in an H.R.T. boiler?
4. How are the inner and outer wrapper sheets on the water legs of a vertical firetube boiler held together.
5. How are tubes fitted to the tube sheets of a firetube boiler?
6. Why do vertical exposed-tube boilers encounter trouble with tubes in the upper tube sheet?
7. What does A.S.M.E. stand for?
8. Why was the Mechanical Inspection Bureau, the Examining Board and the Board of Boiler, Pressure Vessel and Refrigeration Rules instituted?



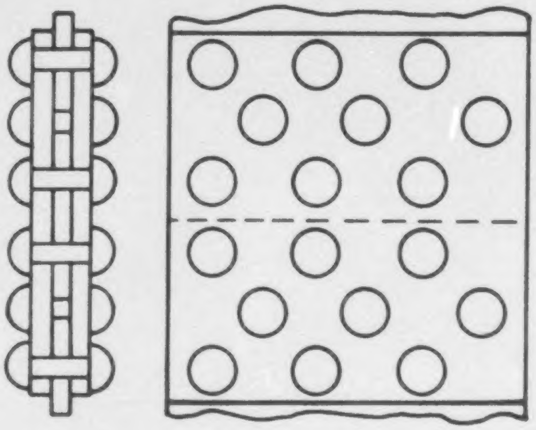
SINGLE RIVETED
LAP JOINT 56% EFFICIENT
3-A-3-1



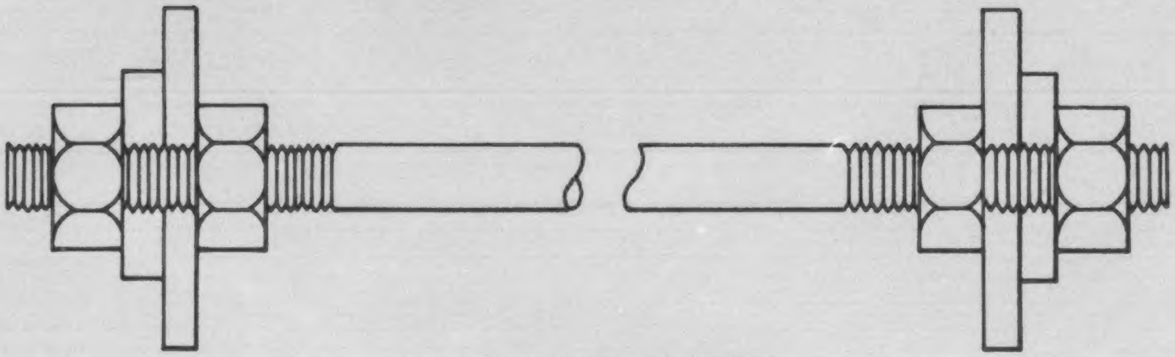
DOUBLE RIVETED
LAP JOINT 70% EFFICIENT
3-A-3-2



TRIPLE RIVETED
LAP JOINT 85% EFFICIENT
3-A-3-3

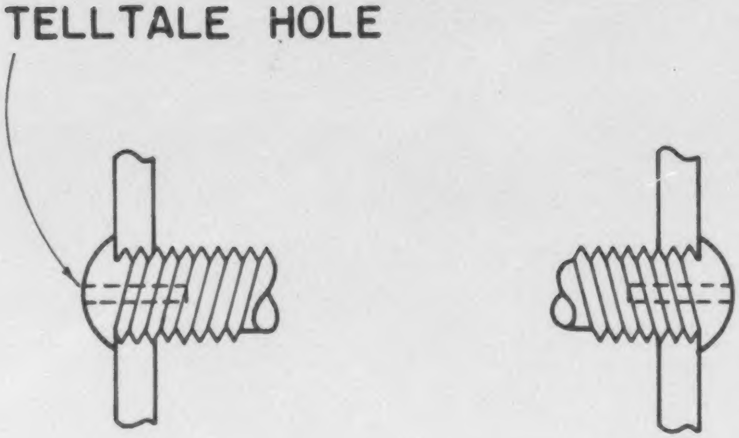


TRIPLE RIVETED
DOUBLE BUTT-STRAP
JOINT 88% EFFICIENT
3-A-3-4



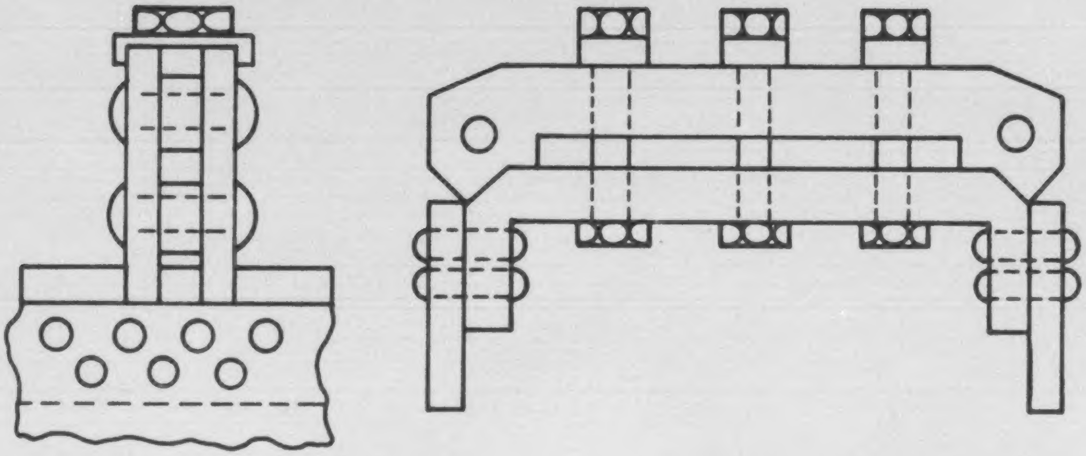
THROUGH STAY

3-A-3-5


TELLTALE HOLE

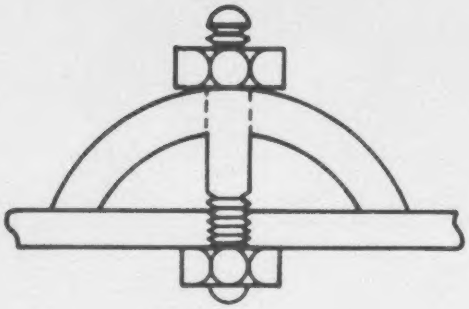
STAY BOLT

3-A-3-6



GIRDER STAY

3-A-3-7



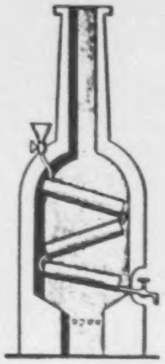
DOG STAY

3-A-3-8

Objective: Be able to describe how the watertube boiler was developed.

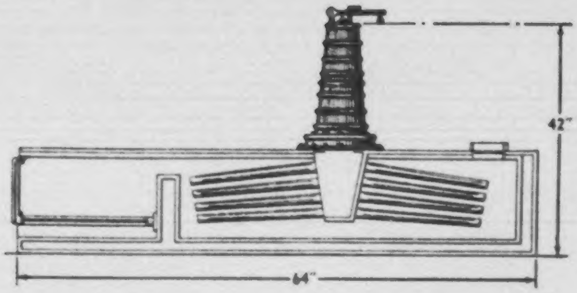
Information: Man has never been satisfied with his environment or his working conditions. Because he is basically lazy he was always looking for easier ways of doing things. He harnessed the oxen and horse to help plow his fields. He used animals to pull his wagons and to transport him over long distances. As our society developed from agricultural to industrial, it was evident that man needed more than animals to help him. Records show that papers were published on the generation of steam as early as 1571. Men like Somerset, Papin, Savery, Newcomen, Desagulier, and Watt were the pioneers who worked to harness steam to benefit man. The first boilers were firetube. With their increase in use because of the industrial revolution of the middle 19th Century, there were a number of explosions. In the interest of safety, men started to look toward the watertube boiler.

The earliest record of a watertube boiler goes back to 1766 when it was patented by William Blakely (Figure 3-B-1-1.)



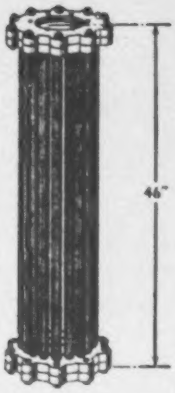
3-B-1-1

Looking at the following sketches you can see how the watertube boiler changed through the years.



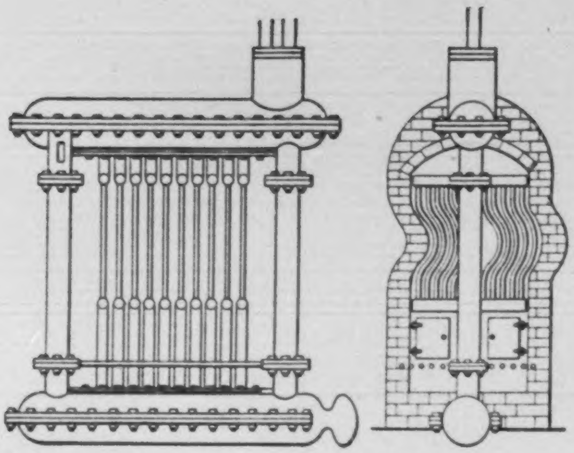
3-B-1-2

John Steven's Porcupine Boiler, 1803
Used on steam boats in the Hudson River.



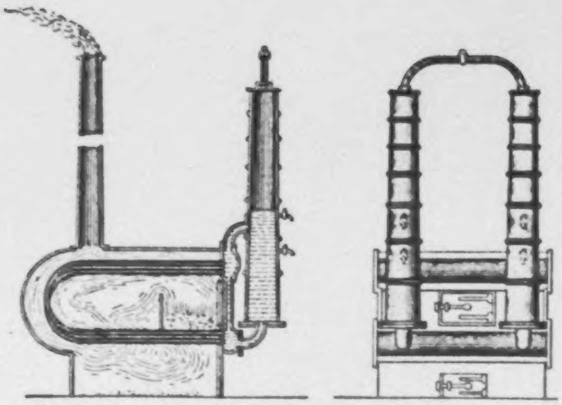
3-B-1-3

His son, John C. Stevens produced a vertical boiler in 1805.



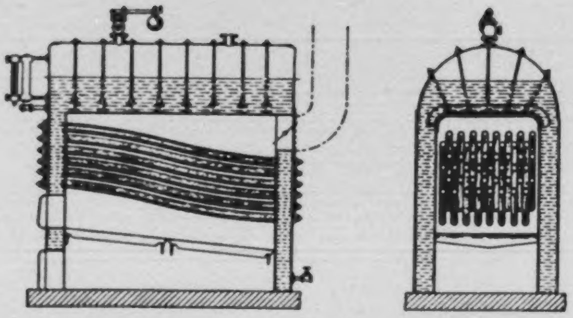
3-B-1-4

The first sectional boiler with well defined circulation was developed in 1825 by Joseph Eve.



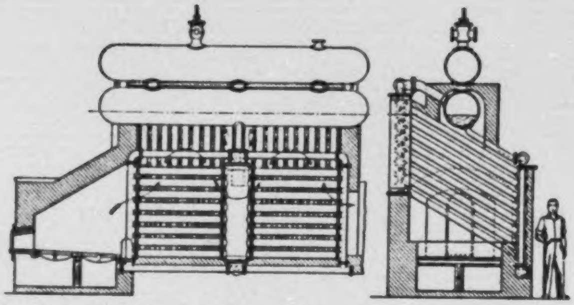
3-B-1-5

Goldsworth Gurney built these boilers for use in his steam carriages in 1826.



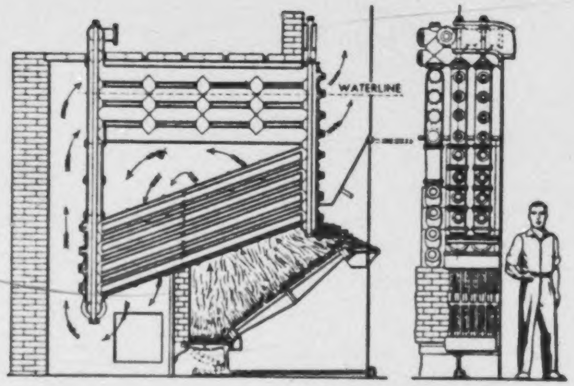
3-B-1-6

Developed by Steven Wilcox in 1856. Was first to use inclined water tubes to connect water spaces at front and rear with steam space above.



3-B-1-7

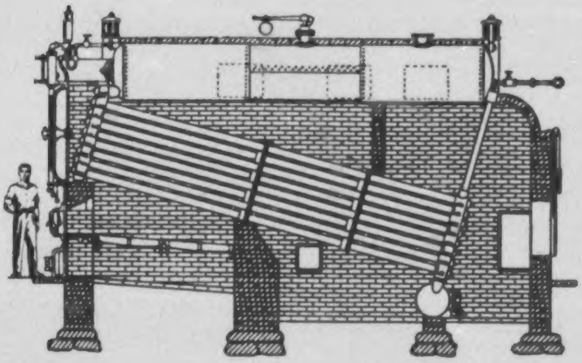
First watertube boiler with inclined tubes in sectional form. Twibill in 1865.



3-B-1-8

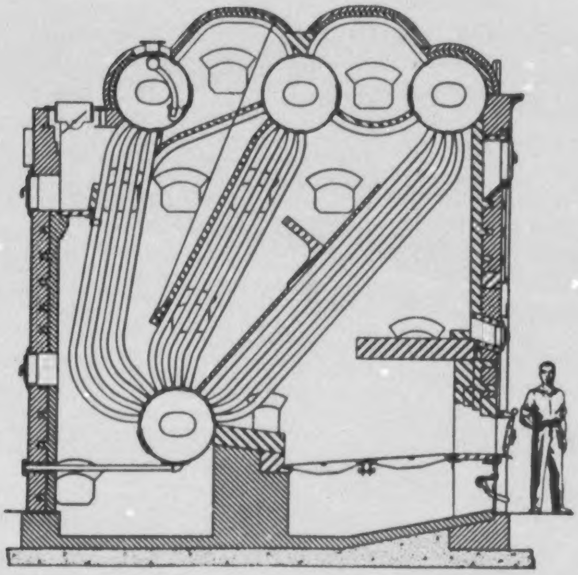
First B. & W. Boiler patented in 1867.

With the rapid growth of industry and the need for more steam at higher pressures, it was only natural that the development of the watertube boiler would make rapid strides. The sketches below will indicate just how great these strides have been.



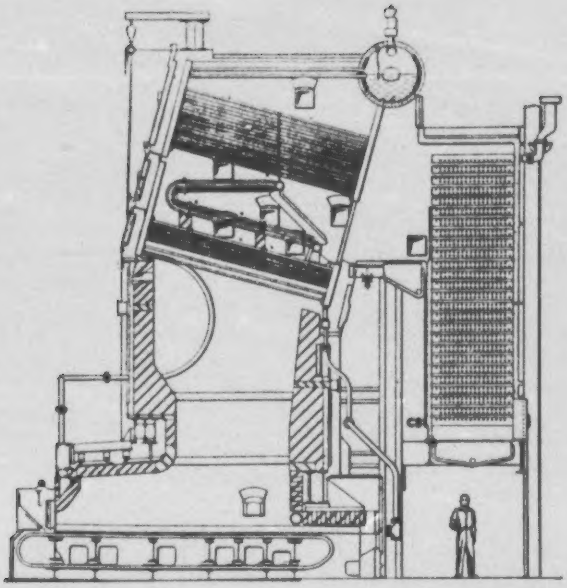
3-B-1-9

B. & W. Boiler developed in 1877.



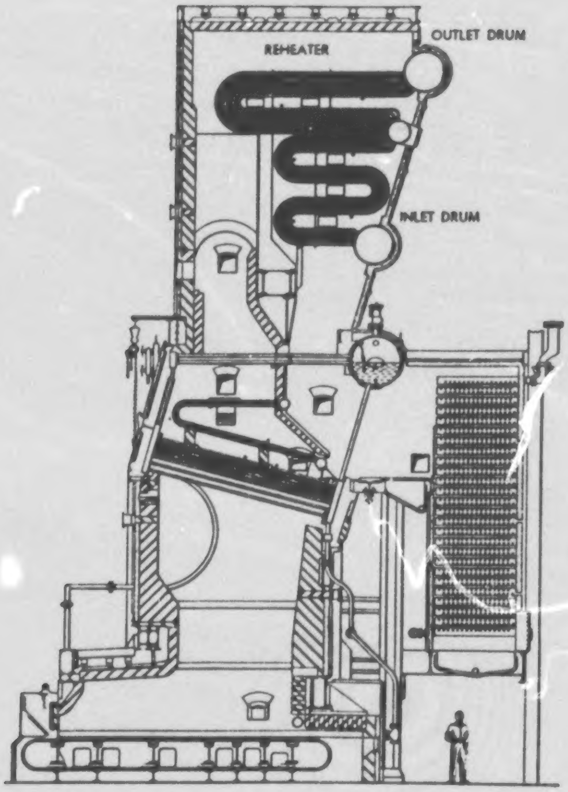
3-B-1-10

Stirling Boiler Set Up for Hand Firing.



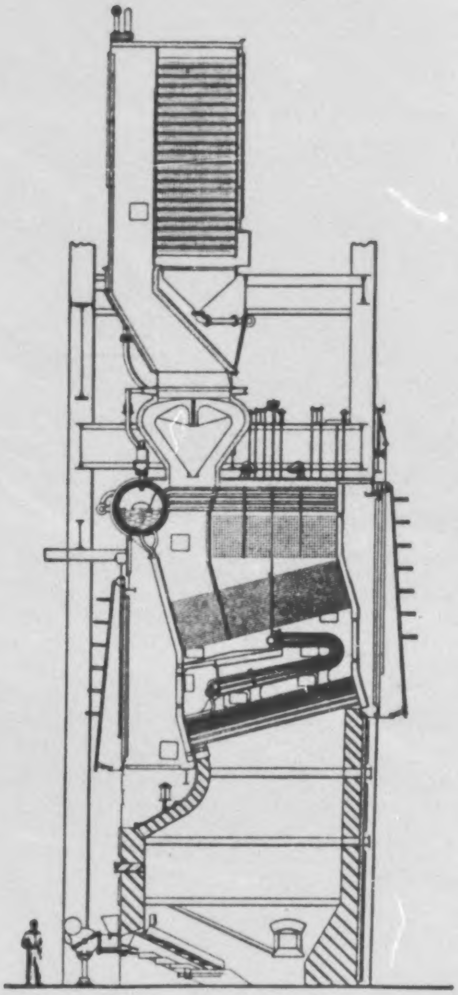
3-B-I-II

1924 Chain Grate Stoker
650 p.s.i. and 750° steam temperature.


OUTLET DRUM
REHEATER
INLET DRUM

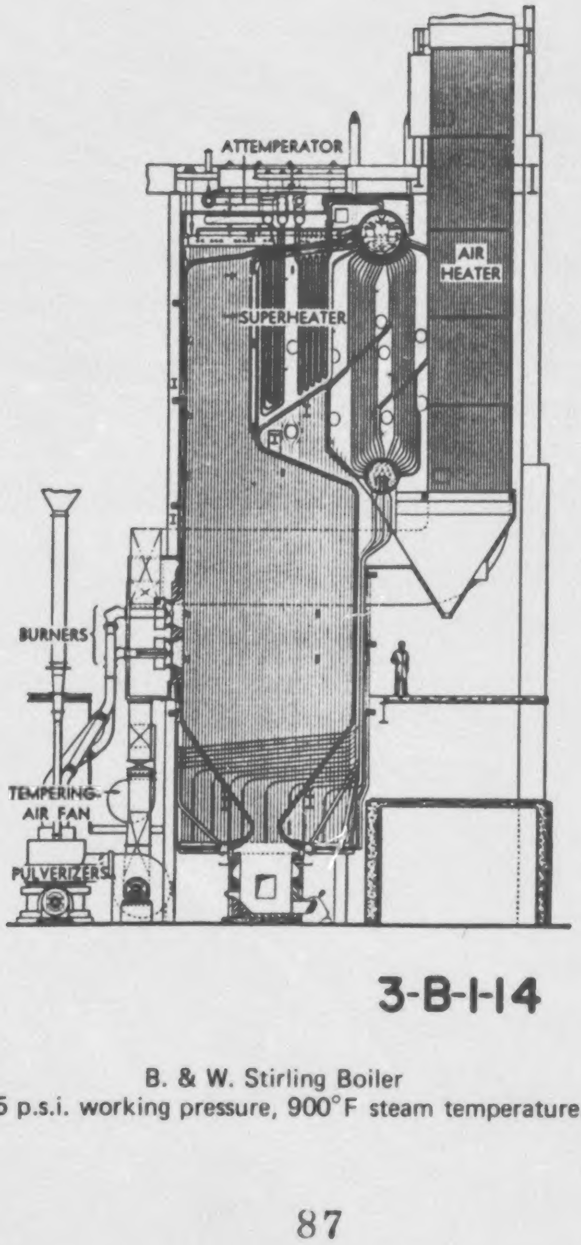
3-B-1-12

1924 B. & W. Boiler with Superheat & Reheat
650 p.s.i. working pressure 750°F temperature and 725°F reheat.



3-B-1-13

1924 B. & W. Boiler
1200 p.s.i. working pressure, 700°F initial and reheat temperatures, with reheat pressure zero at 360 p.s.i.


ATTEMPERATOR
AIR HEATER
SUPERHEATER
BURNERS
TEMPERING AIR FAN
PULVERIZERS

3-B-1-14

B. & W. Stirling Boiler
925 p.s.i. working pressure, 900°F steam temperature.

It should be noted here that the development of the watertube boiler does not mean that there is no place for firetube boilers in industry. The firetube boiler fits in very nicely where moderate pressures are needed and quantities of steam are not too high. Then the firetube boiler can do an excellent job.

Reference: *Steam Plant Operation*

Assignment:

1. Can you explain why the watertube boiler was developed? Explain in detail.
2. Can the firetube or watertube boiler carry a higher pressure? Explain your answer.
3. Is the danger of explosions greâter with the firetube or the watertube boiler? Explain in detail.

Types and Classification of Watertube Boilers — Assignment 3-B-2

Objective: Be able to identify a watertube boiler according to its type and classification.

Information: Boilers can be classified as follows:

1. Vertical or inclined tube
2. According to use – stationary or marine
3. Internally or externally fired.

The types of watertube boilers are:

1. Single or multidrum
2. Straight or bent tube
3. Single or multipass
4. Method of firing – oil, coal, gas, or combination
5. High or low pressure

From this information, you can see how many variations of watertube boilers are possible. When you see a watertube boiler, take the time to classify it.

Reference: *Steam Plant Operation*

Assignment:

1. Briefly describe a vertical and inclined tube boiler.
2. Give some examples of where watertube boilers are used.
3. Explain the difference between internally and externally fired boilers.
4. Are watertube boilers internally and externally fired?
5. Briefly describe a multidrum bent tube boiler and a straight tube boiler.

Objective: Be able to describe the basic construction of a watertube boiler.

Information: All boilers operating in the State of New Jersey must be constructed and installed according to the A.S.M.E. Code. The A.S.M.E. Code was instituted to govern and control the types of material, the methods of construction and procedures of installation of boilers. Boiler material will vary as to boiler temperature and pressures.

It has been found that boiler drums and shells, braces, stays, and tubes will be subject to continual stress and high temperatures when the boiler is in operation. The A.S.M.E. Code makes sure that boilers and fittings are strong enough and made of suitable materials to withstand both forces and temperature. The stresses that must be allowed for are: tension, compression, and shear. Boiler design must also provide for expansion and contraction.

Reference: *Steam Plant Operation*

Assignment:

1. What % of carbon is allowed in the boiler plate? What is the effect of too high a percentage of carbon?
2. Briefly describe the two methods used to manufacture steel used in boiler construction.
3. What stresses must be allowed for in boiler construction?
4. What factors must be considered in determining the maximum allowable working pressure of a boiler?
5. What is meant by factor of safety?
6. How is expansion and contraction taken care of in watertube boilers?
7. Why are drums of watertube boilers made concave rather than flat?
8. Where are stay bolts used on a watertube boiler? Why is this necessary?

Objective: Be able to apply the New Jersey Mechanical Inspection Bureau's rules and regulations as they apply to boilers.

Information: The Mechanical Inspection Bureau in New Jersey was established in the interest of safety in construction and operation of steam boilers and related equipment. The Bureau is interested in safe engineering practices throughout the State for the protection of life and property.

Notice that they always mention safety first before efficiency and protection of property. With this in mind, they have set up rules and regulations that engineers, contractors, owners, lessees, operators and inspectors must adhere to. It is your responsibility to become familiar with these rules and regulations so that you will follow them. It is all in the interest of safety.

The Bureau requires that all boilers covered by these statutes be inspected internally and externally once a year. This inspection must be performed by either a State or an insurance company inspector. The boilers operating in New Jersey must be built and installed in accordance with the A.S.M.E. Code and they must be stamped either New Jersey Standard, New Jersey approved, A.S.M.E., or National Board. After the boiler has had its first inspection, the Bureau will issue the boiler a state number and a boiler certificate. The State number must be stamped, under the direction of the inspector, on the shell of the boiler next to the Manufacturer's stampings in numbers not less than ¼" high. These numbers must also be visibly displayed on the fronts of the boiler. The State number will also be found on the upper left hand corner of the boiler certificate. The boiler certificate, engineer's license, and fireman's license must be displayed in the boiler or engine room under glass.

The boiler certificate is a permanent document, and it should be protected under glass. After each inspection, a new decal will be issued by the State and must be placed on the glass in the lower left-hand corner without disturbing the original document.

Reference: *New Jersey Rules and Regulations*

Assignment:

1. How often must boilers be inspected?
2. What boilers come under the Mechanical Inspection Bureau's inspection requirements?
3. What stamping must be found on boilers in New Jersey?
4. Who issues the boiler registration number? How do you get one? Where must it be displayed?
5. Who issues a boiler certificate? How do you get one? Where must it be displayed? What penalties if any are incurred if it is not posted?

Objective: Be able to apply rules covered in A.S.M.E. Code, Section I, on Power Boilers.

Information: The A.S.M.E. Code is made up of 11 sections. The parts of the code that we are most interested in are Section I – Power Boilers, Section IV – Heating Boilers, Section VI – Recommended Rules for Care and Operation of Heating Boilers, and Section VII – Recommended Rules for Care of Power Boilers.

In order to operate a plant, you must be familiar with what you can and can not do. You must know which repairs you can make, and when it is necessary to call the inspector before certain repairs can be made. The A.S.M.E. Code was established for your safety. Be safe. Know the Code.

Reference: *A.S.M.E. Code,* Section I

Procedure: After studying the information and references, complete the following assignment and be prepared to discuss it in class.

Assignment:

1. Section I of the A.S.M.E. Code is divided into 7 parts and an appendix. Describe each.
2. Besides the symbol, the A.S.M.E. Code requires the manufacturer to stamp certain items on the boiler and on the water walls, superheaters, and steel economizers. Indicate what these items are. This information will be found in Section I.
3. What are the general requirements for feedwater piping in Section I of A.S.M.E. Code?
4. Sketch and label code jurisdictional limits for feedwater piping.

Objective: Be able to describe the types, purpose and location of safety valves.

Information: Every fitting on a boiler is there for a definite positive reason. It is there for safety, efficiency, or safety and efficiency. There is no chrome trim on a boiler; keep that in mind.

Even though every fitting is necessary, the safety valve is considered to be the most important valve on the boiler. Boilers are designed to have a maximum allowable working pressure (M.A.W.P.). If this pressure is exceeded, it could cause a failure on the pressure side of the boiler which could cause a boiler explosion. If there is a sudden drop in pressure without a corresponding drop in temperature, the remaining water will flash into steam causing a violent release of uncontrolled energy. The purpose of the safety valve is to protect the boiler from exceeding its M.A.W.P. It will pop open releasing the steam and will remain open until there is a definite drop in pressure. This is known as blowback or blowdown of a safety.

Safety valves must be located at the highest part of the steam side of the boiler. They must be connected to the boiler shell according to the A.S.M.E. Code with no intervening valves between the safety and the boiler.

The only type of safety valve allowed in New Jersey is the spring-loaded pop-type safety valve. The lever-type and dead-weight safety valves cannot be used because they can be tampered with too easily.

Reference: *Steam Plant Operation*

Assignment:

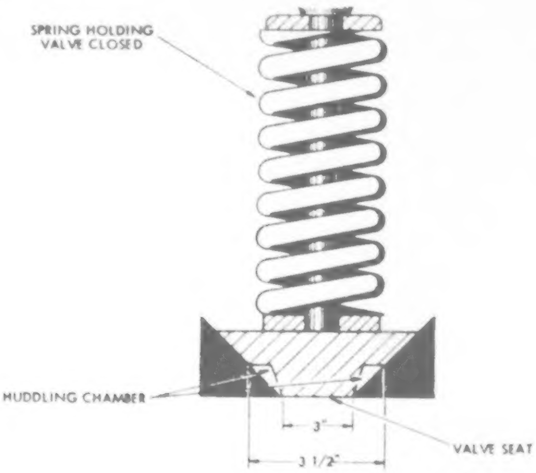
1. List 3 types of safety valves. Which type is allowed? Explain why.
2. Where is the safety valve located on a boiler?
3. Why is the safety valve considered the most important valve on the boiler?
4. What does M.A.W.P. mean?
5. What is meant by blowback or blowdown of a safety valve?
6. How does the safety valve protect the boiler?
7. Will the boiler explode every time there is a failure on the pressure side? Explain your answer.

Objectives:
1. Be able to describe how a safety valve is constructed.
2. Be able to list some of the Code requirements for safety valves.

Information: We have covered the types, purpose, and location of safety valves. Now, let's dig in and find out how and why a safety valve works. The code states every steam boiler must have at least one safety valve; and any boiler having more than 500 square feet of heating surface shall have two or more safety valves. Safety valve capacity must be enough to discharge all the steam that the boiler can generate without allowing the pressure to rise more than 6% above the highest pressure at which any valve is set (and in no case more than 6% above the M.A.W.P.).

A safety valve must be so designed that it will open fully at a predetermined pressure. It must remain open until there is a definite drop in pressure. This is known as a blowback; and it is usually 2 lb. to 8 lb. below popping pressure, but never more than 4% of set pressure. A safety valve must close tight without chattering. Once the valve has reseated, it must remain closed tight. Setting or adjusting safety valves should only be done by a competent person familiar with the construction, operation, and maintenance of safety valves. Repairs should only be done by the manufacturer or his authorized representative.

Normally, whenever we open a valve under pressure, we open it slowly. This is not true with a safety valve; we want it to pop open. This can not happen by accident; it happens by design. Looking at Fig. 4-A-2-1, we have a spring exerting a downward force keeping the valve closed. The steam pressure acting on the safety valve seat is exerting an upward force trying to force the valve to open. The total force trying to overcome the spring pressure is equal to the area of the safety valve seat times the steam pressure.



4-A-2-1

Assuming a steam pressure of 100 p.s.i. and a diameter of 3″, the total force would be:

$$\begin{array}{lll} TF = A \times P & TF & = 3 \times 3 \times .7854 \times 100 \\ & & = 7.0686 \times 100 \\ & & = 706.86 \text{ pounds} \end{array}$$

Where
TF = total force
A = area
P = pressure

So, the spring pressure has to exert a downward force equal to that to keep the valve closed. As soon as the steam pressure starts to overcome the spring pressure, the valve will slowly start to open (feather). This allows the steam to enter a huddling chamber which exposes a larger area for the steam to work on. Naturally, this increases the total upward force causing the safety valve to open quickly, or pop open. Using the dimensions from the sketch, the diameter of the valve plus the diameter of the huddling chamber is 3½″. The total force will then be:

$$\begin{array}{llll} TF = A \times P & TF & = 3.5 \times 3.5 \times .7854 \times 100 & 962.11 \\ & & = 9.6211 \times 100 & \underline{706.86} \\ & & = 962.11 \text{ pounds} & 255.25 \text{ Increase} \end{array}$$

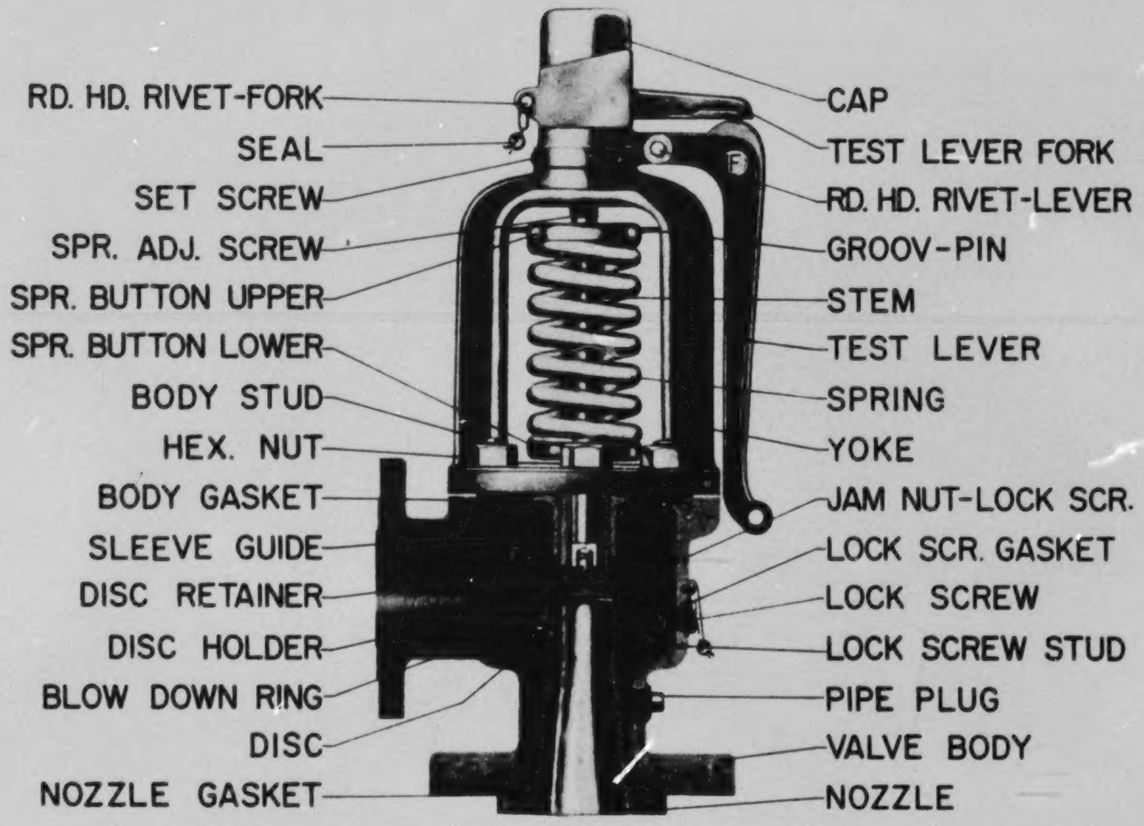
You can see how the total force jumped from 706.86 pounds to 962.11 pounds – an increase of 255.25 pounds which overcomes the spring pressure.

Fig. 4-A-2-2 shows the parts of a spring loaded pop type safety valve, and Fig. 4-A-2-3 shows the recommended piping of the safety valve discharge.

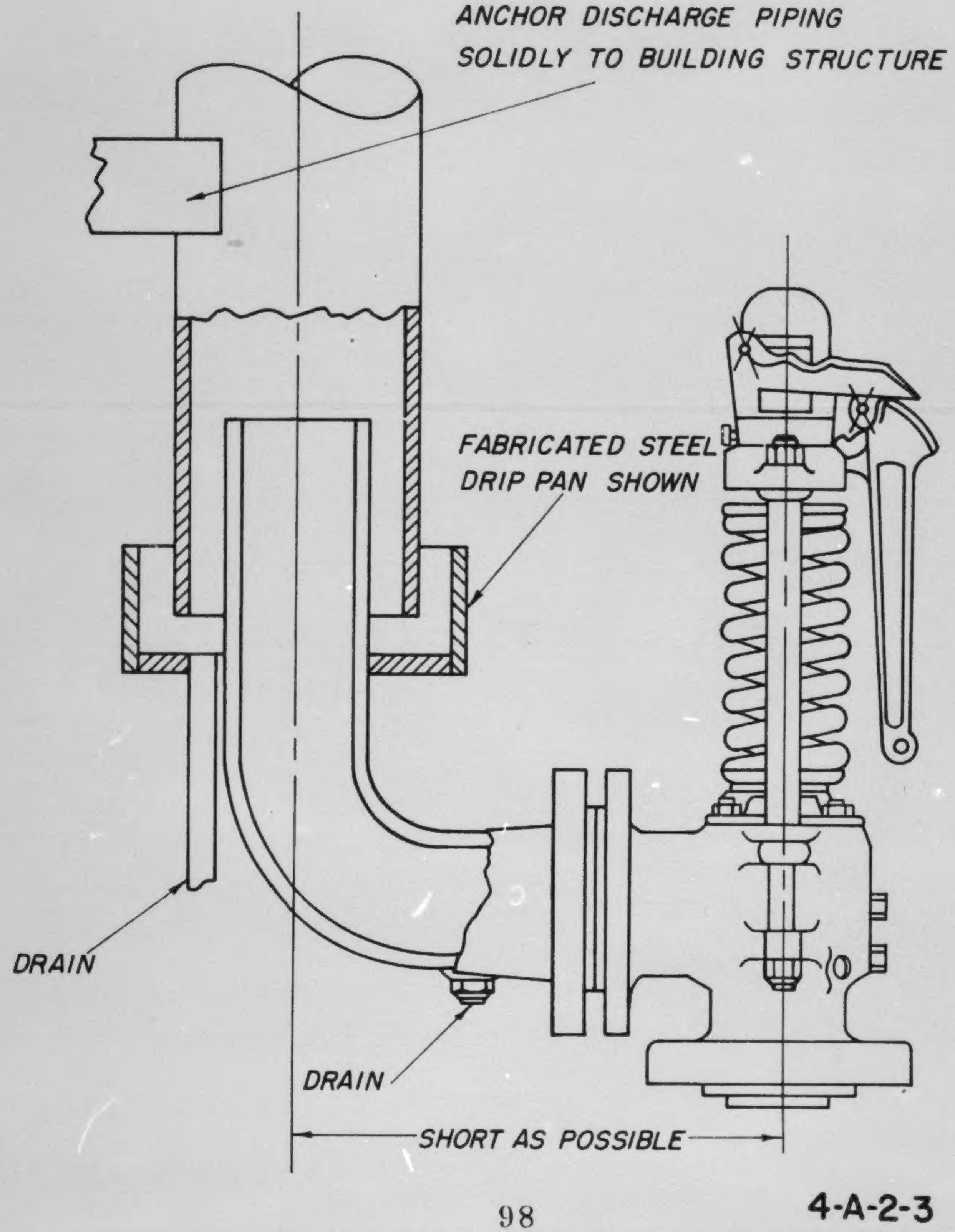
References: *Steam Plant Operation*
A.S.M.E. Code, Section I

Assignment:

1. When is more than one safety valve required on a boiler?
2. What three methods can be used to check safety valve capacity.
3. What are the Code requirements for safety valve capacity?
4. Why are safety valves constructed to pop open? What causes a safety valve to pop open?
5. Who can make adjustments on a safety valve?
6. Who is allowed to replace a new spring on a safety valve?
7. What is meant by blowdown of a safety valve?
8. What is the maximum change possible in spring adjustment of a safety valve?


RD. HD. RIVET-FORK
SEAL
SET SCREW
SPR. ADJ. SCREW
SPR. BUTTON UPPER
SPR. BUTTON LOWER
BODY STUD
HEX. NUT
BODY GASKET
SLEEVE GUIDE
DISC RETAINER
DISC HOLDER
BLOW DOWN RING
DISC
NOZZLE GASKET
CAP
TEST LEVER FORK
RD. HD. RIVET-LEVER
GROOV-PIN
STEM
TEST LEVER
SPRING
YOKE
JAM NUT-LOCK SCR.
LOCK SCR. GASKET
LOCK SCREW
LOCK SCREW STUD
PIPE PLUG
VALVE BODY
NOZZLE

4-A-2-2


ANCHOR DISCHARGE PIPING
SOLIDLY TO BUILDING STRUCTURE
FABRICATED STEEL
DRIP PAN SHOWN
DRAIN
DRAIN
SHORT AS POSSIBLE

4-A-2-3

Safety Valves: Total Force Calculations — Assignment 4-A-2-M1

Objectives:

1. Be able to find total upward force on a safety valve.
2. Be able to transpose and find either the diameter of the safety valve or the popping pressure.

Information: You have already learned that: Total Force = Area times Pressure. In order to find the total force acting on a safety valve, you must know the diameter of the safety valve and the steam pressure. You can use this same formula for finding the diameter of the valve or the popping pressure.

Examples:

1. A boiler carrying 150 p.s.i.g. has a safety valve 3" in diameter. What is the total force on the safety valve?

$$\begin{aligned}
\text{Total Force} &= \text{Area} \times \text{Pressure} \\
\text{Area} &= D^2 \times .7854 \\
\text{Total Force} &= D^2 \times .7854 \times \text{Pressure} \\
&= 3 \times 3 \times .7854 \times 150 \\
&= 7.0686 \times 150 \\
&= 1060.29 \text{ pounds}
\end{aligned}$$

2. A safety valve 3" in diameter has a total force of 1060.29 pounds. What is the popping pressure?

$$\begin{aligned}
\text{Total Force} &= \text{Area} \times \text{Pressure} \\
\frac{\text{Total Force}}{\text{Area}} &= \frac{\text{Area} \times \text{Pressure}}{\text{Area}} \\
\frac{\text{Total Force}}{\text{Area}} &= \frac{\cancel{\text{Area}} \times \text{Pressure}}{\cancel{\text{Area}}} \\
\text{Pressure} &= \frac{\text{Total Force}}{\text{Area}} \\
\text{Pressure} &= \frac{1060.29}{3 \times 3 \times .7854} \\
\text{Pressure} &= \frac{1060.29}{7.0686} \\
\text{Pressure} &= 150 \text{ p.s.i.}
\end{aligned}$$

3. A boiler carrying 150 p.s.i.g. has a safety valve whose spring exerts a downward force of 1060.29 pounds. What diameter safety valve is required?

$$\text{Total Force} = \text{Area} \times \text{Pressure}$$

$$\text{Total Force} = D^2 \times .7854 \times \text{Pressure}$$

$$\frac{\text{Total Force}}{.7854 \times \text{Pressure}} = \frac{\enclose{circle}{D^2} \times .7854 \times \text{Pressure}}{.7854 \times \text{Pressure}}$$

$$\frac{\text{Total Force}}{.7854 \times \text{Pressure}} = \frac{D^2 \times \cancel{.7854} \times \cancel{\text{Pressure}}}{\cancel{.7854} \times \cancel{\text{Pressure}}}$$

$$D^2 = \frac{\text{Total Force}}{.7854 \times \text{Pressure}}$$

$$\sqrt{D^2} = \sqrt{\frac{\text{Total Force}}{.7854 \times \text{Pressure}}}$$

$$D = \sqrt{\frac{\text{Total Force}}{.7854 \times \text{Pressure}}}$$

$$= \sqrt{\frac{1060.29}{.7854 \times 150}}$$

$$= \sqrt{\frac{1060.29}{117.81}}$$

$$= \sqrt{9}$$

$$= 3''$$

Assignment:

1. Using the formula for total force, develop the formula for:
    a. Popping pressure
    b. Diameter of safety valve
2. A boiler carries 100 p.s.i.g.; the total downward force of the safety valve spring is 1256.6 pounds. Find the diameter of the safety valve.
3. A boiler carrying 200 p.s.i.g. has a safety valve 2½" in diameter. Find the total upward force.
4. A boiler safety valve 2½" in diameter has a spring that exerts a downward force of 736.305 pounds. Find its popping pressure.
5. A safety valve 3" in diameter has a steam pressure of 250 p.s.i.g. acting on it. The huddling chamber increases the diameter of the valve to 3½". Find the following:
    a. Area of safety valve
    b. Area of huddling chamber.
    c. Total force on safety valve.
    d. Total force on huddling chamber.
    e. Increase in total force due to huddling chamber.

Bottom Blowdown Valves: Types, Location and Purpose — Assignment 4-B-1

Objectives:

1. Be able to describe the types of blowdown valves.
2. Be able to locate and describe the purpose of blowdown valves.
3. Be able to blowdown a boiler using the bottom blowdown valves.

Information: All raw water (city water) contains a certain amount of scale-forming salts. These scale-forming salts start to settle out when the temperature of the water reaches about 150°F. These salts settle on the boiler heating surface which insulates the surface and causes the boiler to overheat and burn out. To prevent this from happening, chemicals are added to the boiler water to turn these scale-forming salts into a non-adhering sludge. The sludge will stay in suspension and settle to the lowest part of the waterside of the boiler, when the boiler is at a light load. It is at this point that we have bottom blowdown lines and bottom blowdown valves.

Boilers operating at 100 p.s.i. or over are required to have two blowdown valves. The two valves may be two slow-opening valves, or one quick-closing valve and one screw-type valve. If a quick-closing valve is used, it must be the valve closest to the shell of the boiler. In blowing down, the quick-closing valve should be opened first and closed last. It is only a sealing valve. The slow-opening valve which is farthest from the shell of the boiler is the blowing valve. It is the valve taking all the wear and tear of blowing down.

The four reasons for using the bottom blowdown valves are:

1. Remove sludge and sediment.
2. Control high water.
3. Control chemical concentration.
4. Dump boiler for cleaning and inspection.

You must always have pressure on the boiler when blowing down. The only time you have no pressure is when you are dumping the boiler. Remember, before you can dump a boiler, it must be cool.

The best time to blow down a boiler is at its lightest load. This is when the sludge and sediment will have had a chance to settle to the bottom of the waterside of the boiler. The procedure to follow when blowing down a boiler is:

1. First check your water level.

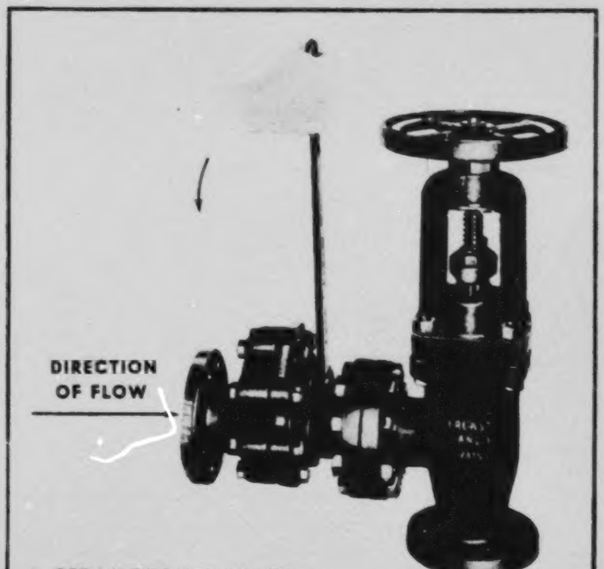
2. Open quick-closing valve first; then open the slow-opening valve. Open valves slowly, but open them wide open.

3. If you can not see the gage glass while blowing down, have someone else watch it.

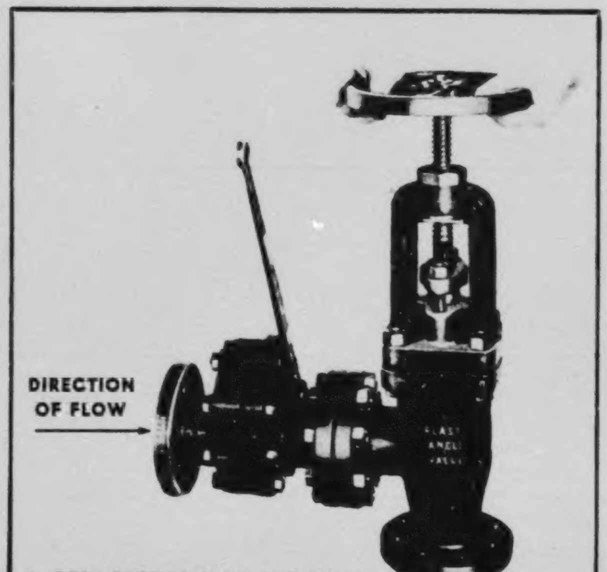
4. Close the slow-opening valve first and the quick-closing valve last.

Note: *Never* walk away from an open blowdown valve. Keep your hands on the valve until it is closed.

OPENING SEQUENCE

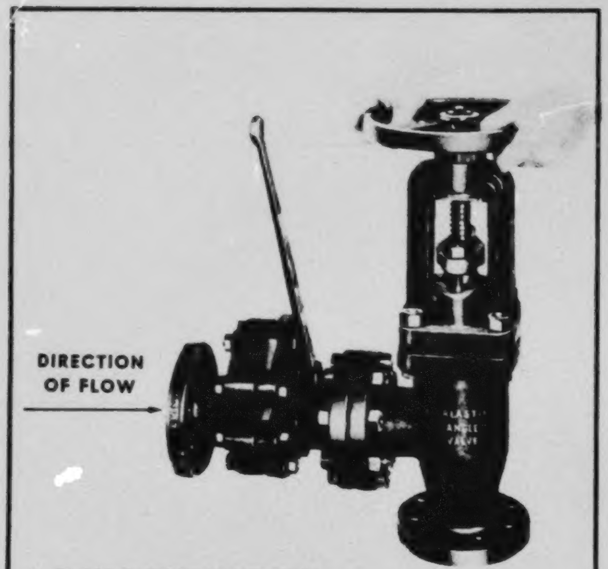


1. OPEN INSIDE VALVE FIRST

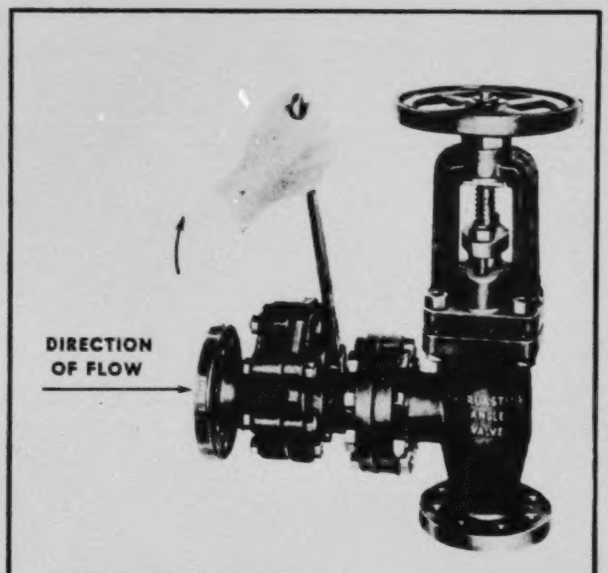


2. OPEN OUTSIDE VALVE AND BLOW

CLOSING SEQUENCE



3. CLOSE OUTSIDE VALVE FIRST



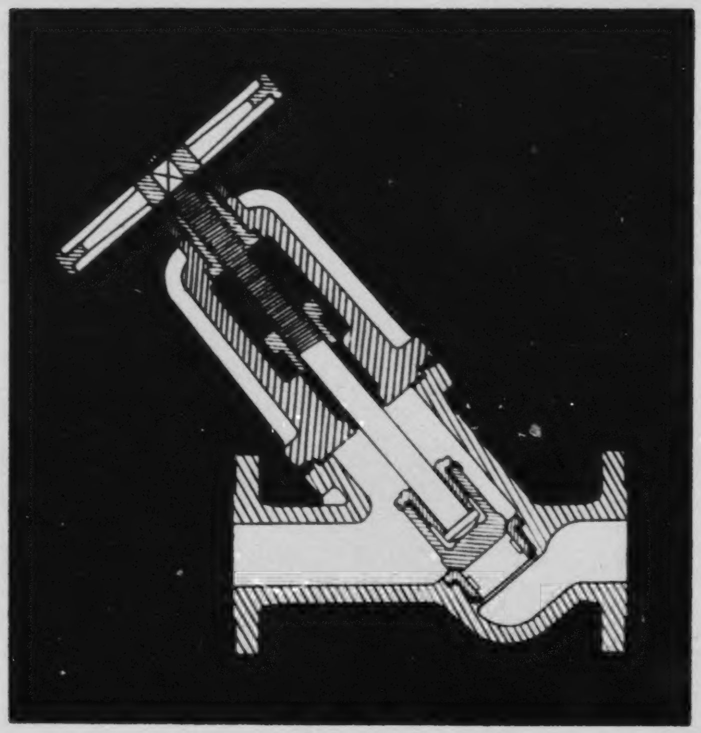
4. CLOSE INSIDE VALVE LAST

In following this procedure, the valve next to the boiler is operated in still water.

This minimizes the possibility of damage to the sealing faces, preserving the valve next to the boiler as a leak-tight sealing unit, and letting the outside, or blowing valve take the punishment during the initial opening and final closing while an erosive flow of water is passing through the valve.

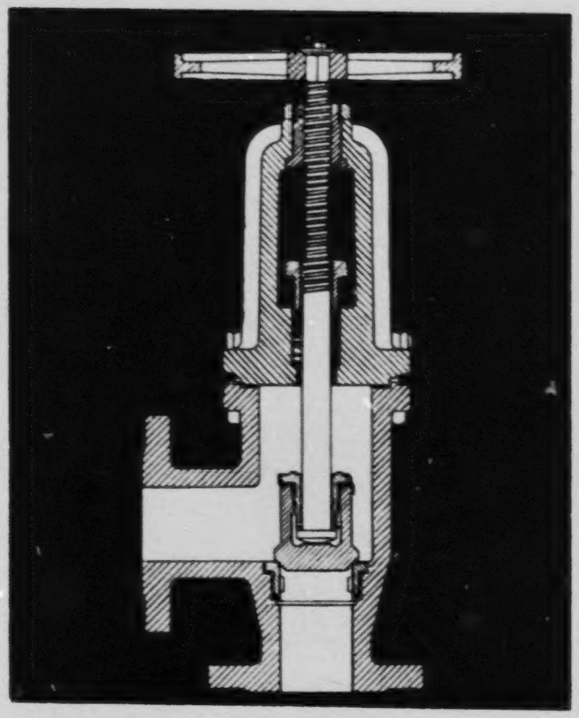
Operating the valves in this sequence is not only sound practice from a safety viewpoint, but also makes it unnecessary to empty the boiler should repairs to the actual blowing valve become necessary.

Sequence of Operation to follow when blowing down a boiler.



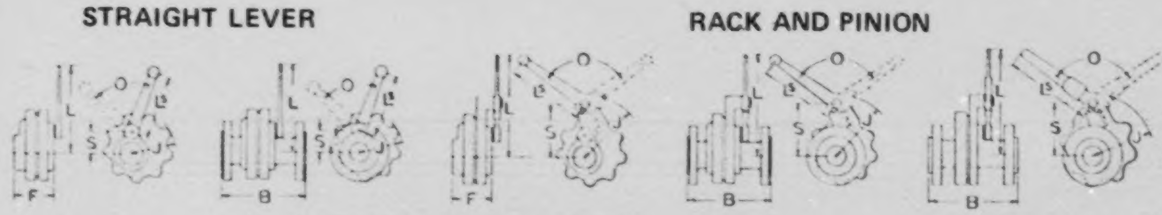
"Y" valve type of slow-opening blowdown valve

4-B-1-2

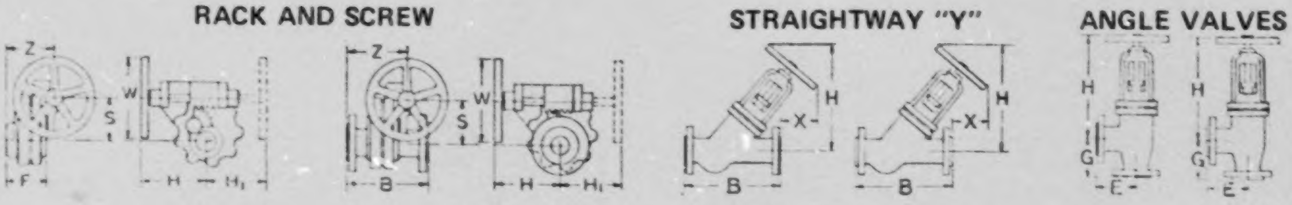


Angle valve type of slow-opening blowdown valve

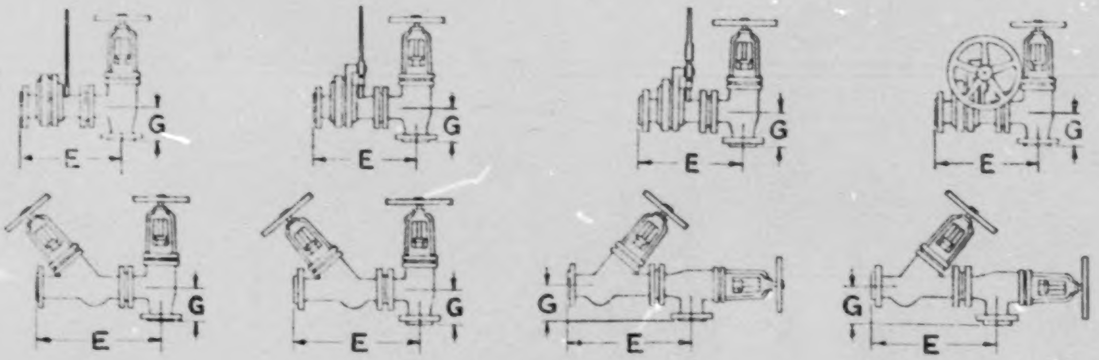
4-B-1-3


STRAIGHT LEVER
RACK AND PINION
O
L
S
J
F
B

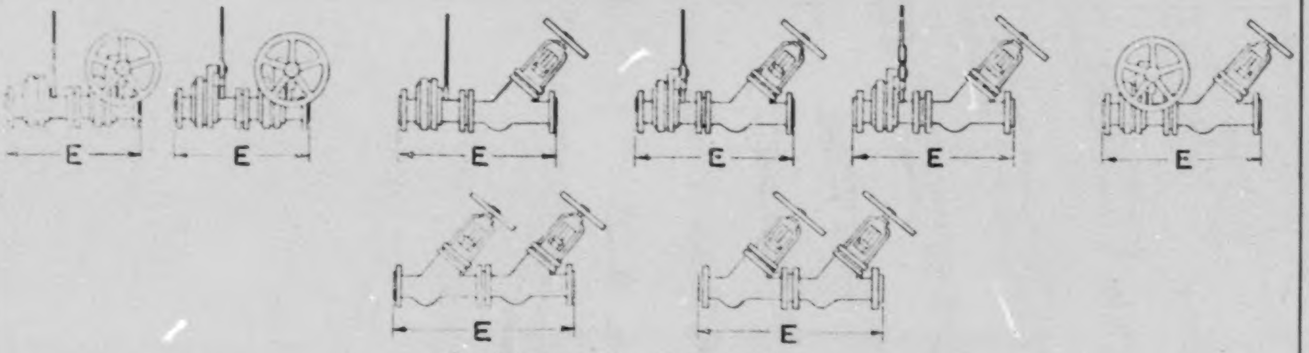
Quick-opening straightway valves


RACK AND SCREW
STRAIGHTWAY "Y"
ANGLE VALVES
Z
W
S
F
H
H₁
B
X
G
E

Slow-opening straightway valves



Angle type duplex units



Straightway type duplex units

Combinations of Blowdown Valves
(Letters indicate needed dimensions)

4-B-1-4

Reference: *Steam Plant Operation*

Procedure: After studying the information and reference, complete the following assignment and be prepared to discuss it in class.

Assignment:

1. List four reasons for using the bottom blowdown valves.
2. If a quick-opening valve is used on a blowdown line, where must it be located?
3. When is the best time to blow down a boiler?
4. What procedure would you follow in blowing down a boiler with a quick-closing valve and a screw-type valve?
5. What is meant by a slow-opening valve?
6. Where are blowdown lines located on:
   a. firetube boiler?
   b. watertube boiler?

Construction and Code Requirements of Bottom Blowdown Valves — Assignment 4-B-2

Objectives:

1. Be able to explain why there are construction requirements for blowdown valves.
2. Be able to list some of the Code requirements for bottom blowdown valves.

Information: When blowing down a boiler, the blowdown lines are subjected to full boiler pressure and temperature. They are subjected to this pressure and temperature without the luxury of warming up slowly. The lines and valves must be designed to stand this strain and a suitable means must be provided for expansion. Boilers carrying over 100 p.s.i. with the exception of high temperature water, traction or portable, must have two blowdown valves. Straight run globe valves, or valves that would allow dams or pockets to exist, could collect sediment and shall not be used.

References: *A.S.M.E. Code,* Sections I and VII.
Steam Plant Operation

Procedure: After studying information and references, complete the following assignment and be prepared to discuss it in class.

Assignment:

1. What type of material is required for valves when the pressure exceeds 100 p.s.i.?
2. What are the material requirements for valves when the pressure exceeds 200 p.s.i.?
3. What is the maximum size of a surface blowoff line?
4. What are the minimum and maximum sizes of a bottom blowoff line?
5. When must extra heavy piping be used on blowoff lines?
6. What does the Code mean when it states, "A slow-opening valve"?
7. Why can't you use a straight-run globe valve as a blowdown valve?
8. Discuss Code requirements about the following:
    - a. Maintenance of blowoff equipment.
    - b. Protection against freezing.
    - c. Care in blowing down.
    - d. Frequency of blowing down.
    - e. Blowing down water walls.
    - f. Draining a boiler.
    - g. Care before entering drum or shell of boiler.
    - h. Flushing a boiler.

Objective: Be able to describe the construction of a water column and how it works.

Information: Last year, you learned that the purpose of a water column is to slow down the turbulance of the boiler water. Then you can get a truer reading of the water level in the gage glass. So, the water column must be located at the normal operating water level. The exact location according to Code will be discussed in the next unit.

Figure 4-C-1 shows a cutaway view of a water column. Observe the location of the gage glass and try cocks. With a normal operating water level (about half a glass), you would get steam and water when you open the middle try cocks. Steam should come out of the top and water should come out the bottom. The top float will warn of high water and the bottom float will warn of low water. You can see the advantage of having a sediment chamber by the position of the bottom float. It wouldn't take much sludge to cause the low water float to hang up.

The gage glass and water column should be blown down at least once a shift. This not only helps to establish the water level in the boiler; it also clears both gage glass, and water column lines and the sediment chamber of any sludge or sediment.

Any leaks around the gage glass should be given instant attention. A leaky gage glass will give a false water level reading. It will also cause the glass to thin out and eventually rupture.

A gage glass should be kept clean. When cleaning the inside of a gage glass, use a wooden dowel and a piece of rag. Never use a metal rod when cleaning a gage glass. If you scratch the inside of the glass, the action of the steam and water will cause the glass to thin out and it will break.

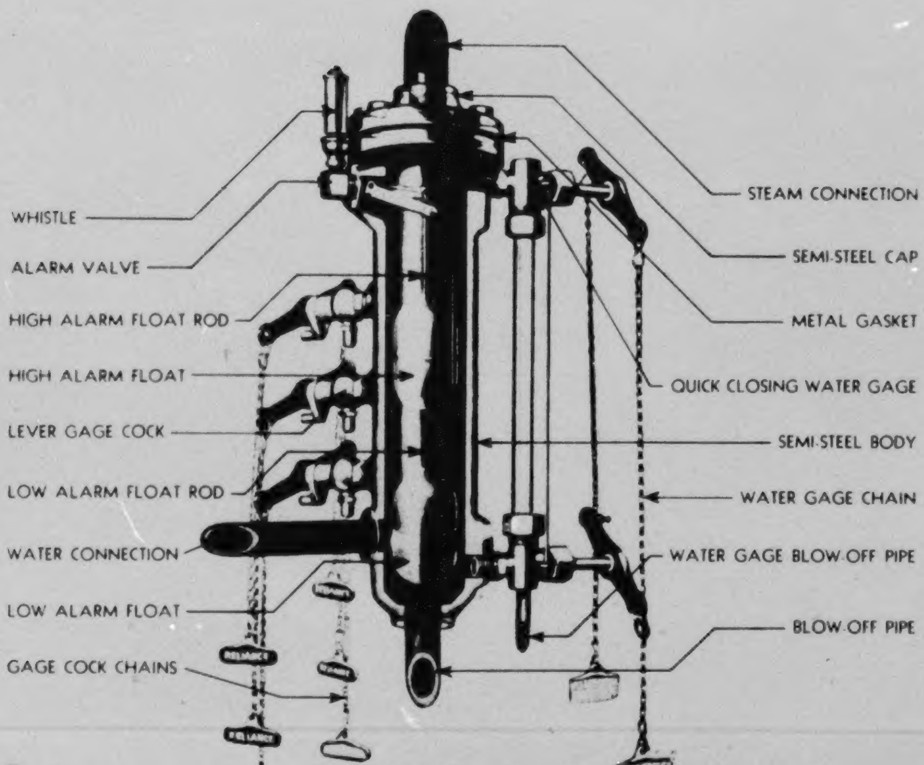
Whenever a gage glass is replaced or taken down for cleaning, always replace the gage glass washers. Never place the glass back in service using old washers. If it is necessary to work on the gage glass when the boiler is on the line, shut off both steam and water to the gage glass, and open the gage glass blowdown valve to relieve all the pressure. Wear safety goggles, and never touch a hot glass with a cold wrench; it might cause the glass to rupture.

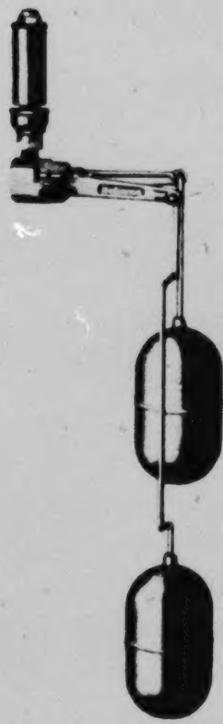
Shutoff valves are provided between the gage glass and the water column, so that the gage glass can be isolated from the column and a new glass installed under pressure.

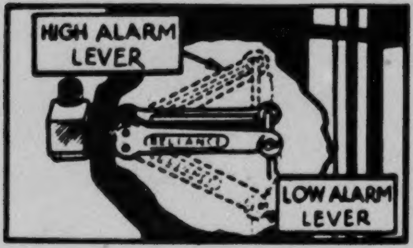
Reference: *Steam Plant Operation*

Assignment:

1. What is the purpose of a water column?
2. Why are try cocks necessary if a boiler has a gage glass?
3. With a normal operating water level, what comes out of the middle try cock – when it is opened?
4. What is the purpose of the floats inside the water column?
5. How often should a water column be blown down? Why?
6. If the top line to the gage glass is closed or clogged, what would your gage glass indicate?
7. If the bottom line to the gage glass is closed or clogged, what would the gage glass indicate?
8. How would you go about replacing a broken gage glass with your boiler under pressure?
9. Why is it important to keep gage glass nuts from leaking?
10. Why is it necessary to shut off steam and water valves to the gage glass while making adjustments on packing nuts?


WHISTLE
ALARM VALVE
HIGH ALARM FLOAT ROD
HIGH ALARM FLOAT
LEVER GAGE COCK
LOW ALARM FLOAT ROD
WATER CONNECTION
LOW ALARM FLOAT
GAGE COCK CHAINS
STEAM CONNECTION
SEMI-STEEL CAP
METAL GASKET
QUICK CLOSING WATER GAGE
SEMI-STEEL BODY
WATER GAGE CHAIN
WATER GAGE BLOW-OFF PIPE
BLOW-OFF PIPE




HIGH ALARM LEVER
RELIANCE
LOW ALARM LEVER

Water Column: Location and Code — Assignment 4-C-2

Objectives:

1. Be able to locate the water column.
2. Be able to describe the Code requirements on water columns.

Information: It is important that the water column be at its proper location. It could mean the difference between burning up a boiler or causing severe plant damage due to carryover.

The water column must be located at the normal operating water level, so that the lowest visible part of the gage glass is 2" to 3" above the highest heating surface. How do you know when its safe to add water to a boiler? If you can see water in the bottom of the gage glass or you can get water from the bottom try cock, it is safe to add water to your boiler. Why? Because the water column must be located at the normal operating water level, so that the lowest visible part of the gage glass is 2" to 3" above the highest heating surface.

The location of the water column and gage glass should be checked to make sure that it is in its proper place. This can be done by external measurement. Or, when the boiler is off the line, add water until it is visible in the gage glass, then drop a ruler in through the manhole until it hits the top of the highest heating surface. Remove ruler and see how wet it is. It should show 2" to 3" of water.

Figures 4-C-2-1, 4-C-2-2, and 4-C-2-3 show the location of the water column on three types of boilers.

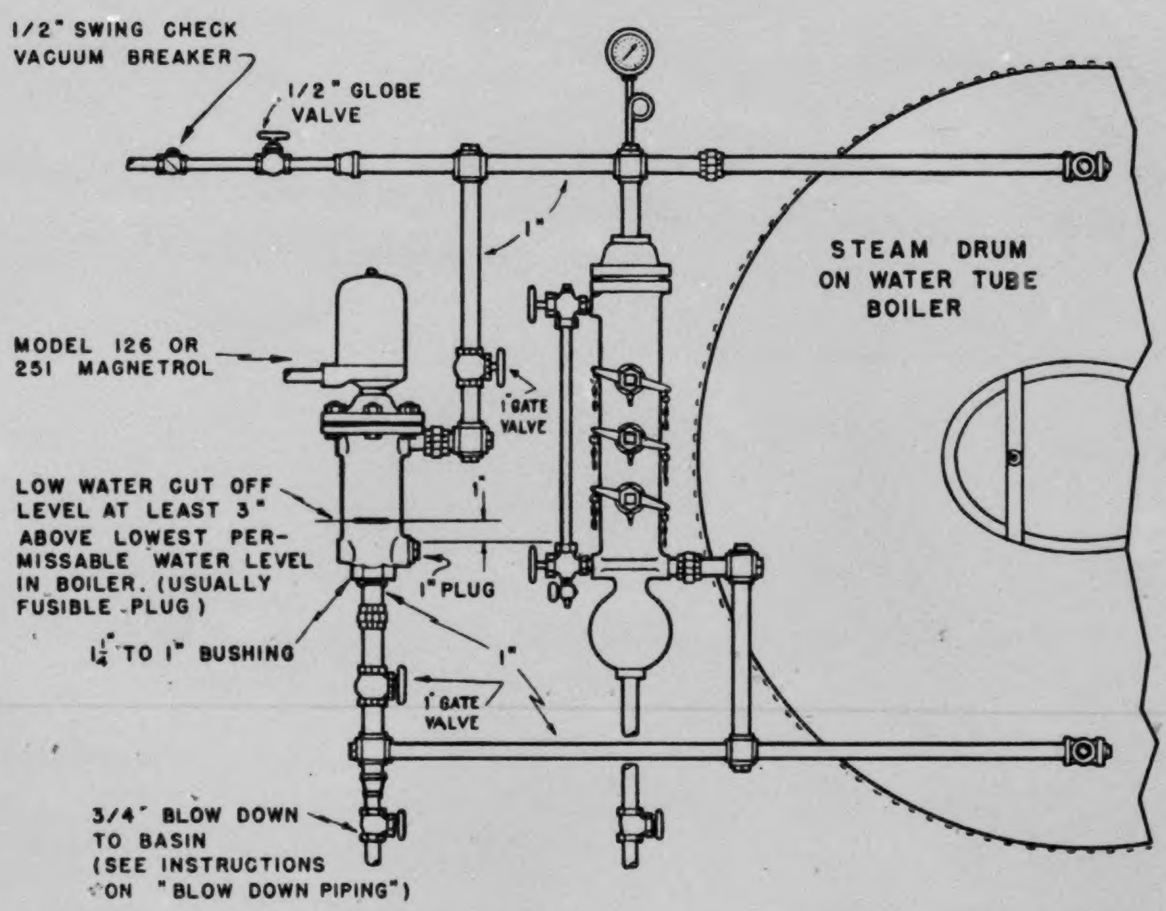
References:

A.S.M.E. Code, Section I.
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

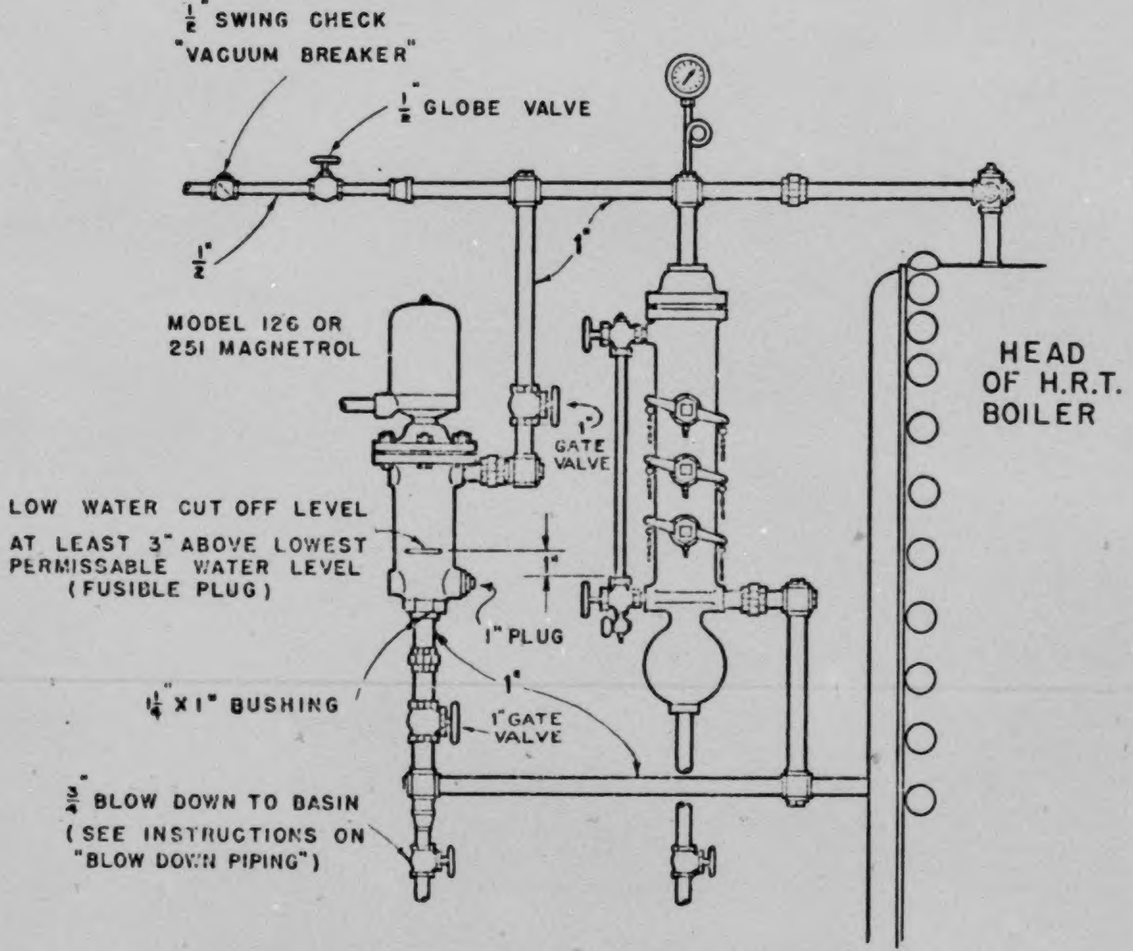
1. How can you be sure it is safe to add water to a boiler? Explain your answer.
2. How can you check to see if the water column is at its proper location?
3. What is the minimum pipe size connecting the water column to the boiler?
4. What are the Code requirements for water column blowdown lines?
5. What type of material can be used in water columns for pressures up to 250 p.s.i.? For pressures up to 350 p.s.i.? For pressures over 350 p.s.i.?

6. What are the Code requirements for valves on lines between the water column and the boiler?
7. Where are cross fittings used when piping up a water column?
8. Does the Code require that all boilers have a water column?


1/2" SWING CHECK VACUUM BREAKER
1/2" GLOBE VALVE
1"
STEAM DRUM ON WATER TUBE BOILER
MODEL 126 OR 251 MAGNETROL
1" GATE VALVE
LOW WATER CUT OFF LEVEL AT LEAST 3" ABOVE LOWEST PERMISSABLE WATER LEVEL IN BOILER. (USUALLY FUSIBLE PLUG)
1"
1" PLUG
1¼" TO 1" BUSHING
1"
1" GATE VALVE
3/4" BLOW DOWN TO BASIN (SEE INSTRUCTIONS ON "BLOW DOWN PIPING")

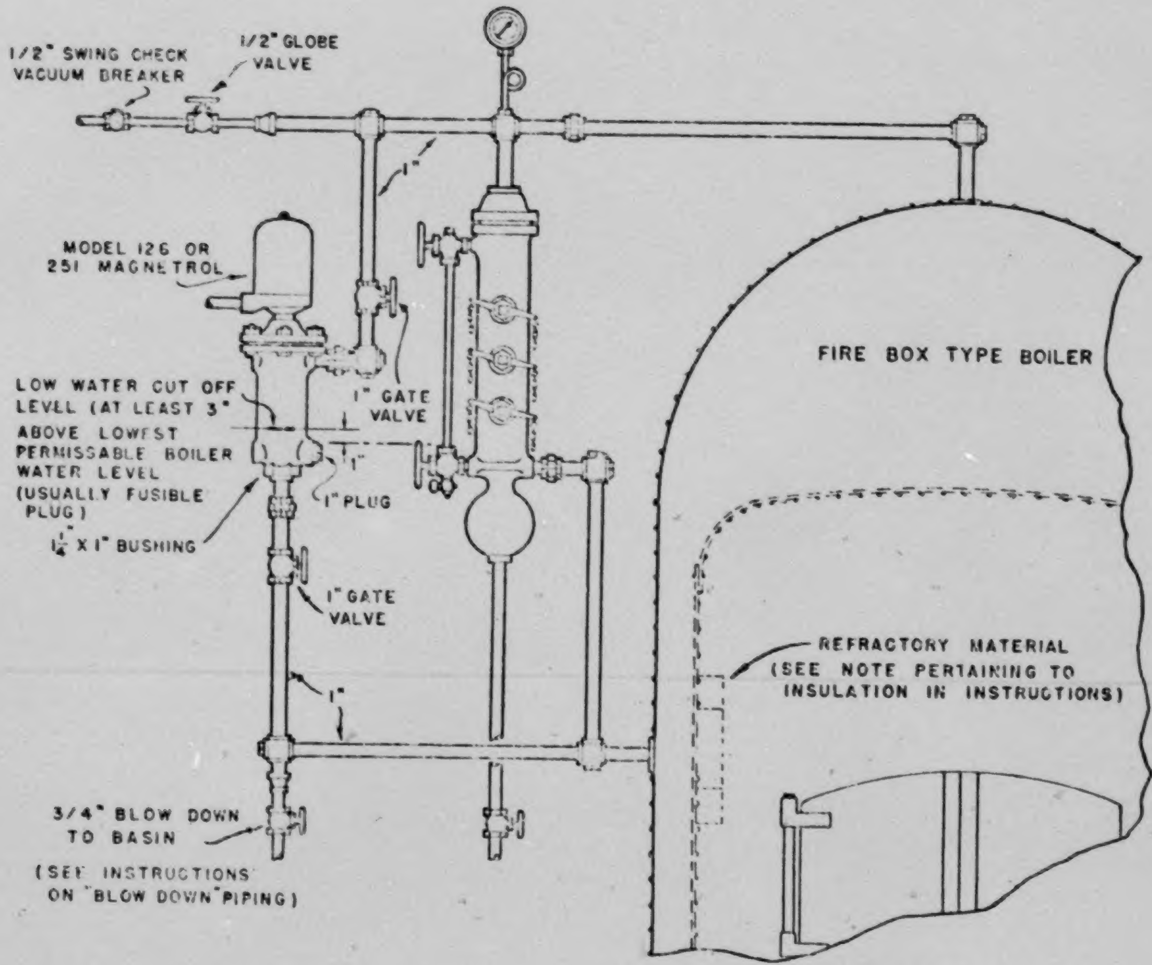
INSTALLATION ON WATER TUBE BOILERS

4-C-2-1


½" SWING CHECK
"VACUUM BREAKER"
½" GLOBE VALVE
½"
1"
MODEL 126 OR
251 MAGNETROL
1" GATE VALVE
HEAD
OF H.R.T.
BOILER
LOW WATER CUT OFF LEVEL
AT LEAST 3" ABOVE LOWEST
PERMISSABLE WATER LEVEL
(FUSIBLE PLUG)
1"
1" PLUG
1¼" X 1" BUSHING
1"
1" GATE
VALVE
¾" BLOW DOWN TO BASIN
(SEE INSTRUCTIONS ON
"BLOW DOWN PIPING")

INSTALLATION ON HORIZONTAL RETURN TUBULAR BOILERS

4-C-2-2


1/2" SWING CHECK VACUUM BREAKER
1/2" GLOBE VALVE
1"
MODEL 126 OR 251 MAGNETROL
LOW WATER CUT OFF LEVEL (AT LEAST 3" ABOVE LOWEST PERMISSABLE BOILER WATER LEVEL (USUALLY FUSIBLE PLUG)
1" GATE VALVE
1"
1" PLUG
1¼" X 1" BUSHING
1" GATE VALVE
1"
3/4" BLOW DOWN TO BASIN
(SEE INSTRUCTIONS ON "BLOW DOWN" PIPING)
FIRE BOX TYPE BOILER
REFRACTORY MATERIAL (SEE NOTE PERTAINING TO INSULATION IN INSTRUCTIONS)

INSTALLATION ON FIREBOX TYPE BOILERS

4-C-2-3

Objectives:

1. Be able to identify the various types of steam gages.
2. Be able to locate and to describe the purpose of steam gages.

Information: Steam gages are used on boilers to indicate the pressure being carried in the boiler.

Boiler plants have pressure gages to indicate all the various pressures an operator needs to insure safe and efficient plant operation. They will include suction and discharge pressures on fuel and water lines, air pressure, gas pressure, and steam pressure.

Pressure gages are calibrated in pounds per square inch. This is the pressure above atmospheric pressure and is known as gage pressure. Absolute pressure is gage pressure plus atmospheric pressure.

A pressure gage with its pointer pointing to 50 on the face of a gage would be read as 50 pounds per square inch. This is written as 50 p.s.i. or 50 p.s.i.g. If an operator were asked how much pressure was on the above gage, he would answer 50 pounds.

A vacuum gage is calibrated in inches or mercury below atmospheric pressure. A vacuum gage with its pointer pointing to 4 on the face of a gage would be read as 4 inches of mercury below atmospheric pressure. This is written as 4"Hq. If an operator were asked how much suction he had on the above gage, he would reply 4".

Remember:

Pressure gage is read in pounds.
Vacuum gage is read in inches.

Figures 4-D-1-1 and 4-D-1-2 are examples of gage faces indicating standard ranges possible. Observe how graduations on faces will vary. For example, on a gage range 0 to 30 p.s.i., each graduation is ½ pound, and on the range 0–300 p.s.i., the graduations are in 5 p.s.i. steps.

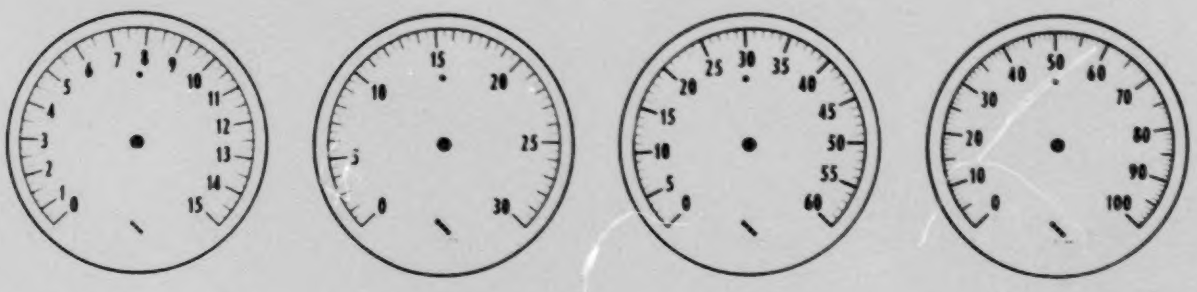
A boiler steam pressure gage should have a range of two times the safety valve setting, and it cannot be less than one and one half times the safety valve setting at any time. This means that when ordering a new boiler pressure gage, it is necessary to know your safety valve setting.

The boiler pressure gage should be connected to the highest part of the steam side of a boiler, and it must be easily seen from the operating floor. It must be cleaned, well lighted and free from vibration. The boiler pressure gage must be protected by a siphon. The siphon forms a water leg preventing live steam from entering the bourdon tube. If steam is allowed to enter the bourbon tube at any time, the gage must be tested. It is important that the gage be checked periodically to insure its accuracy.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

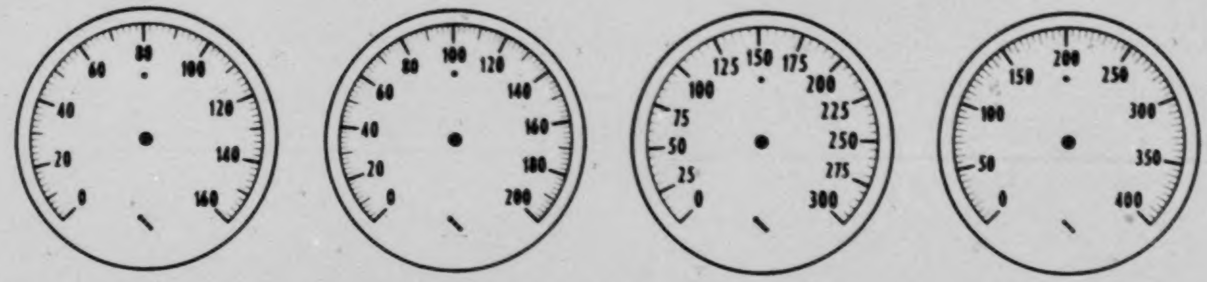
Assignment:

1. What is the purpose of a boiler pressure gage?
2. If the range of a boiler pressure gage is 0 lbs. to 300 lbs., what would the approximate popping pressure of the boiler be?
3. What procedure would you have to follow if live steam were allowed to enter a bourdon tube?
4. What does p.s.i.g. and p.s.i.a. mean? How is each found?
5. What kind of gage would read 5"?
6. How can you recognize a compound pressure gage?
7. What are gages that record pressure above the atmosphere called, and how are they calibrated?
8. What are gages that record pressure below the atmosphere called, and how are they calibrated?


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 5 10 15 20 25 30
0 5 10 15 20 25 30 35 40 45 50 55 60
0 10 20 30 40 50 60 70 80 90 100

0 to 15 p.s.i. 0 to 30 p.s.i. 0 to 60 p.s.i. 0 to 100 p.s.i.

4-D-1-1


0 20 40 60 80 100 120 140 160
0 20 40 60 80 100 120 140 160 180 200
0 25 50 75 100 125 150 175 200 225 250 275 300
0 50 100 150 200 250 300 350 400

0 to 160 p.s.i. 0 to 200 p.s.i. 0 to 300 p.s.i. 0 to 400 p.s.i.

4-D-1-2

Steam Pressure Gages: Code, Calibration, and Range — Assignment 4-D-2

Objective: Be able to describe the Code requirements for steam pressure gages.

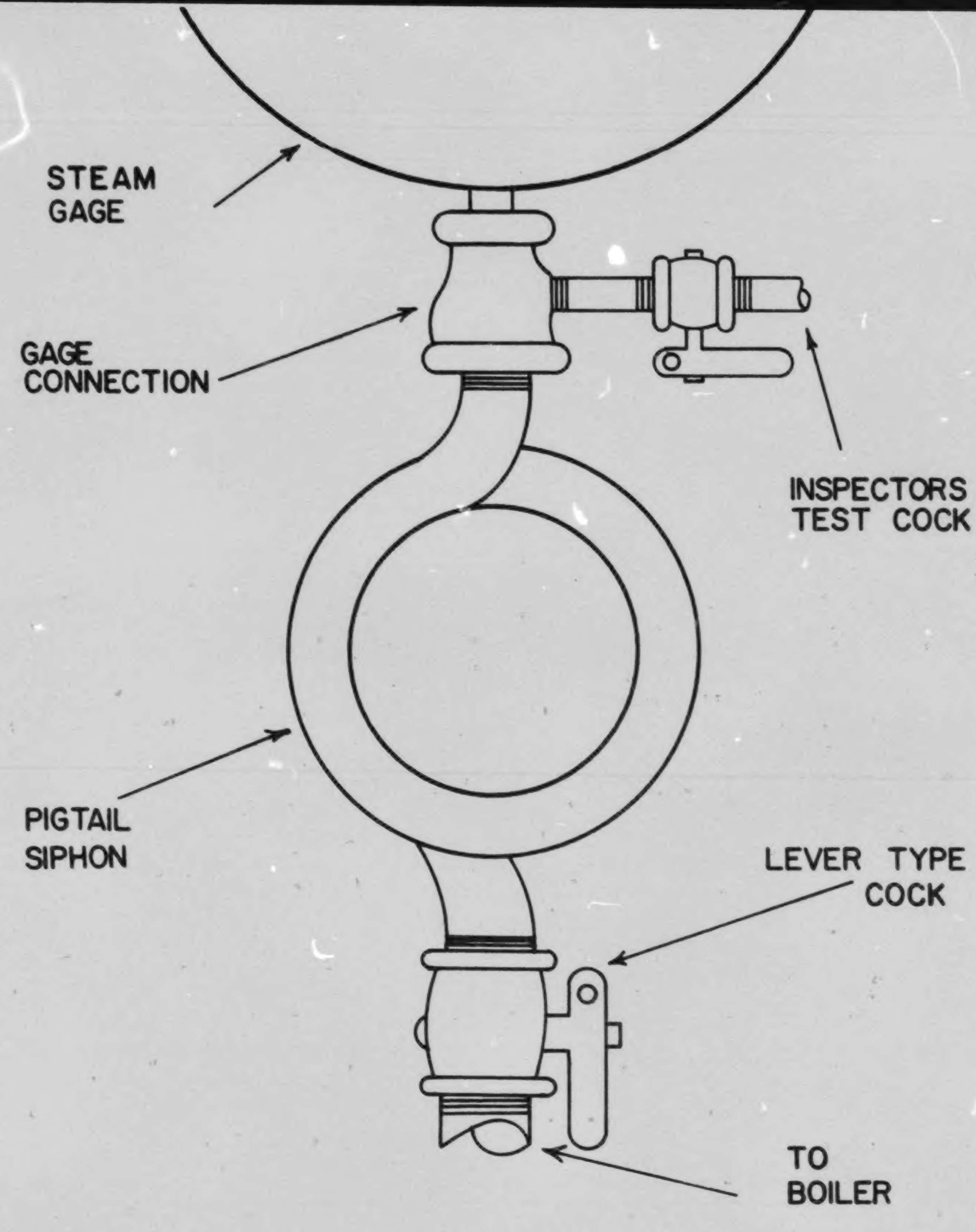
Information: The A.S.M.E. Code requires that each boiler shall have its own pressure gage. The steam gage must connect to the highest part of the steam side of the boiler. It must be easily seen from the operating platform, and kept clean, well lighted, and protected from extreme heat or cold. A siphon or similar device must be installed to protect the bourdon tube from live steam. Brass or copper pipe may be used for temperatures up to 406°F. The dial of the pressure gage should be graduated to approximately double the safety valve setting, and in no case less than 1½ times the safety valve setting. This is known as the range of a steam gage. The gages shall also be graduated so that the pointer will be in a nearly vertical position when at its normal operating pressure.

Figure 4-D-2-1 shows a suggested arrangement for piping up a boiler pressure gage. Observe that the shutoff valves should be lever-handle cocks that show by their position whether they are open or closed. The Code also states that an additional valve or cock may be located near the boiler, it must be locked or sealed open.

Reference: *A.S.M.E. Code,* Section I and Section VII.

Assignment:

1. Why does the A.S.M.E. Code require a siphon or similar device before a steam pressure gage?
2. Why must the valves used with steam gages be lever-type valves?
3. Explain why the Code requires the steam pressure gage used on boilers to have a range of twice, or at least 1½ times, the safety valve popping pressure?
4. What is the maximum temperature allowed on brass and copper pipe or tubing?
5. What is the minimum pipe size when using steel and wrought iron pipe or tubing in hooking up a steam pressure gage?
6. What is the minimum size of a siphon on a steam gage?


STEAM GAGE
GAGE CONNECTION
INSPECTORS TEST COCK
PIGTAIL SIPHON
LEVER TYPE COCK
TO BOILER

4-D-2-1

Objectives:

1. Be able to explain why steam gages have to be corrected.
2. Be able to correct a steam gage.

Information: You may remember from your related unit on pressure gages that the pressure gage must be connected to the highest part of the steam space of a boiler. It must also be visable to the fireman. This presents a problem on boilers that have steam drums 40-50 feet or more above the floor plates.

It means a line must run from the top of the steam drum down to where the gage is visable to the operator. And for every vertical foot of piping filled with water, there is a pressure of .433 pounds.

The factor, .433 is obtained in the following manner.

1 cubic foot of water weighs 62.4 pounds at 60°F.

Therefore a column of water 1 foot high with a cross section of 1 square inch at 60°F exerts a pressure of $\frac{62.4}{144}$ or .433 pounds. (144 square inch in one square foot.)

So, it is possible to convert pounds per square inch to feet of water by dividing by .433.

If we have a 100 ft. high pipe filled with water and put a pressure gage at the bottom, it would read 100 × .433 or 43.3 pounds.

If a pressure gage is located 20 feet below the steam drum, it would read 20 × .433 or 8.66 pounds with no pressure on the boiler. If this boiler was carrying 100 pounds of steam the gage would read 100 + 8.66 or 109 p.s.i. 9 pounds more than was actually carried in the steam drum. It would be necessary to correct the gage 9 pounds.

References:

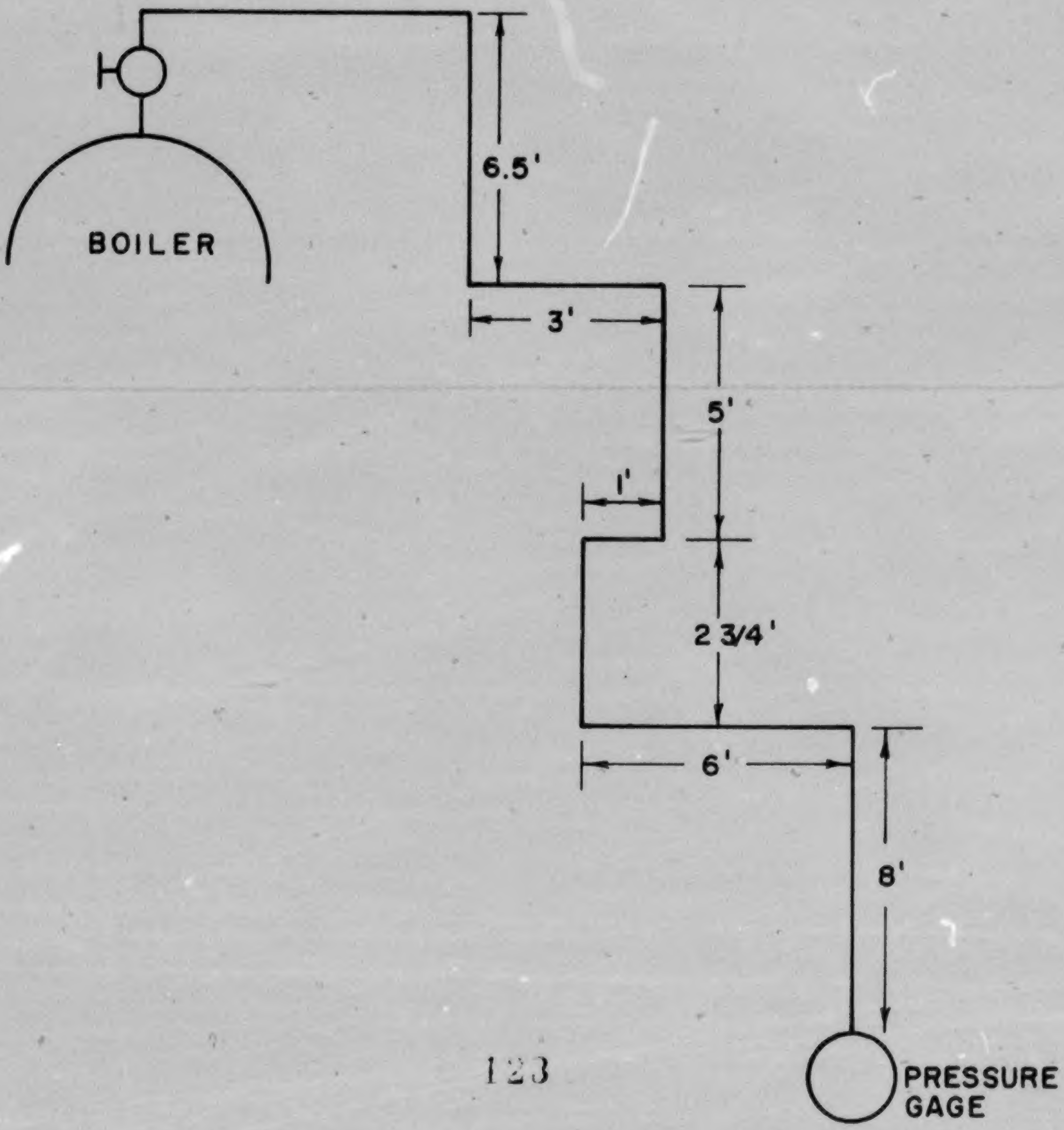
Steam Plant Operation
Elementary Steam Power Engineering

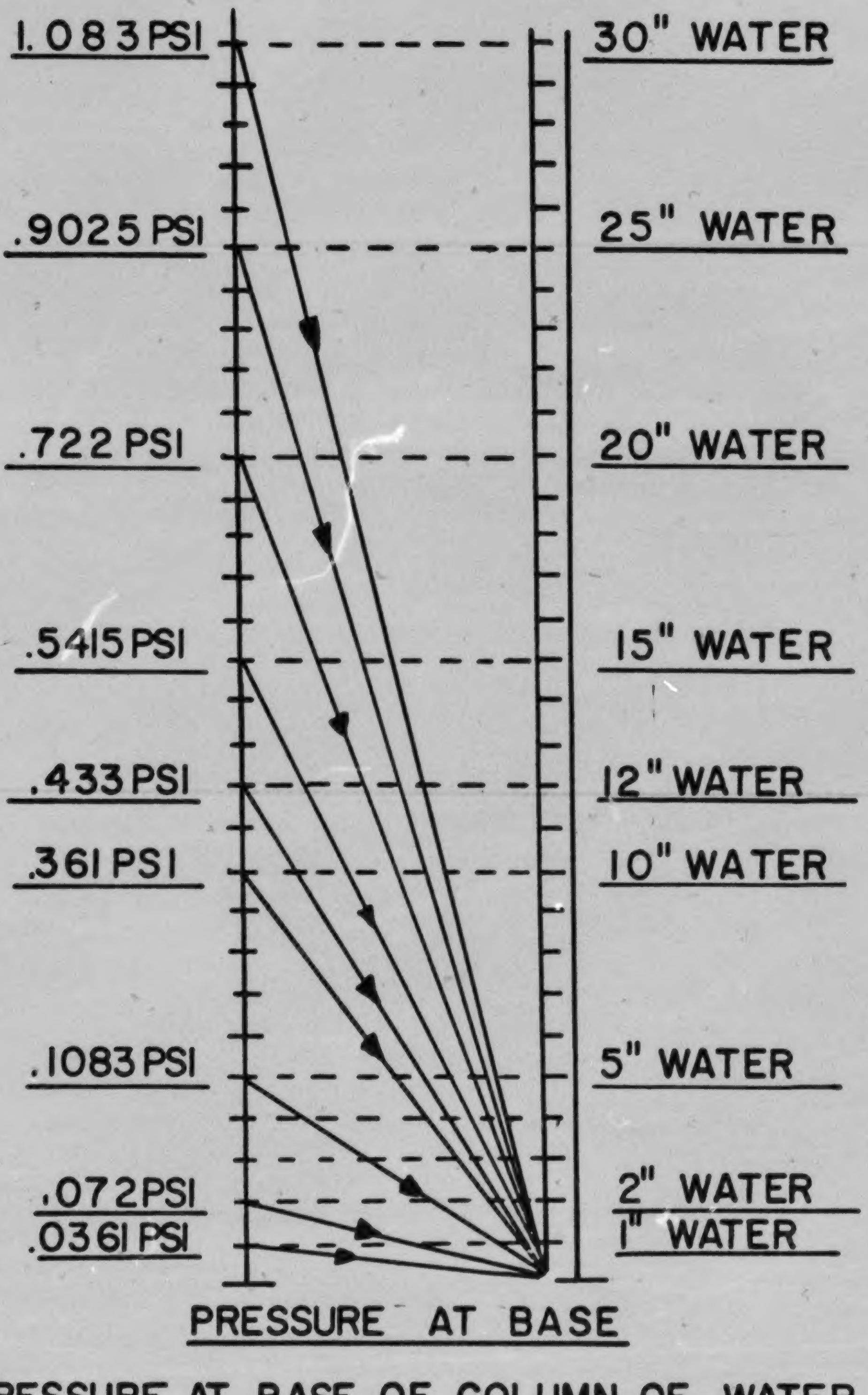
Assignment:

1. A pressure gage is located 35 feet below the steam drum. The boiler carries 135 p.s.i.g. If the pressure gage had not been corrected, what will it read?

2. A stand pipe is located in a boiler room and is made of 3½" diameter pipe. It is 250 feet high. How much pressure will it show on a gage connected to the bottom when it is:
   a. 1/3 full
   b. 1/2 full
   c. full
3. A pressure gage located 30 feet below the steam and water drum. It has been corrected and shows 207 p.s.i. What will a gage read that is located at the top of the drum?

4. Boiler pressure 185 p.s.i.. Find pressure if gage has not been corrected.




1.083 PSI
30" WATER
.9025 PSI
25" WATER
.722 PSI
20" WATER
.5415 PSI
15" WATER
.433 PSI
12" WATER
.361 PSI
10" WATER
.1083 PSI
5" WATER
.072 PSI
2" WATER
.0361 PSI
1" WATER
PRESSURE AT BASE

PRESSURE AT BASE OF COLUMN OF WATER

.0361 PSI FOR EACH VERTICAL INCH

4-D-2-M1

Internal Feed Line: Description and Function — Assignment 4-E-1

Objectives:

1. Be able to describe what an internal feed line is.
2. Be able to explain why internal feed lines are necessary.

Information: It is important that the feed water is introduced into the boiler so that it will not come in contact with the boiler heating surface exposed to direct radiation or hot gases of combustion at any time. When pressures are 400 pounds or over, the Code requires that the feed water inlet through the drum be fitted with a shield or sleeve (or some suitable method) to reduce the effects of temperature differential in the head or boiler shell. If needed the discharge end of a feed pipe should be fitted with a baffle to divert the flow from riveted joints.

Remember, the incoming feed water is relatively cold when compared to the temperatures in the fire box. If this water were allowed to impinge directly on the boiler heating surface, it would subject it to severe thermal shock. This could be compared to jumping into a lake with a water temperature of 60°F when the outside temperature is 100°F.

The Code also requires that seamless steel pipe equal to Schedule 80 (extra heavy) be used for pressure over 100 p.s.i. and temperatures over 220°F.

The internal feed line in steam drums of watertube boilers extends about 80% of the length of the drum. It is installed so that the incoming feed water is discharged below the surface of the water. See figure 4-E-1-1.

In H.R.T. boilers over 40" in diameter the feed line shall enter above the central row of tubes. It will discharge at about three-fifths the length from the end of the boiler subjected to the hottest gases of combustion.

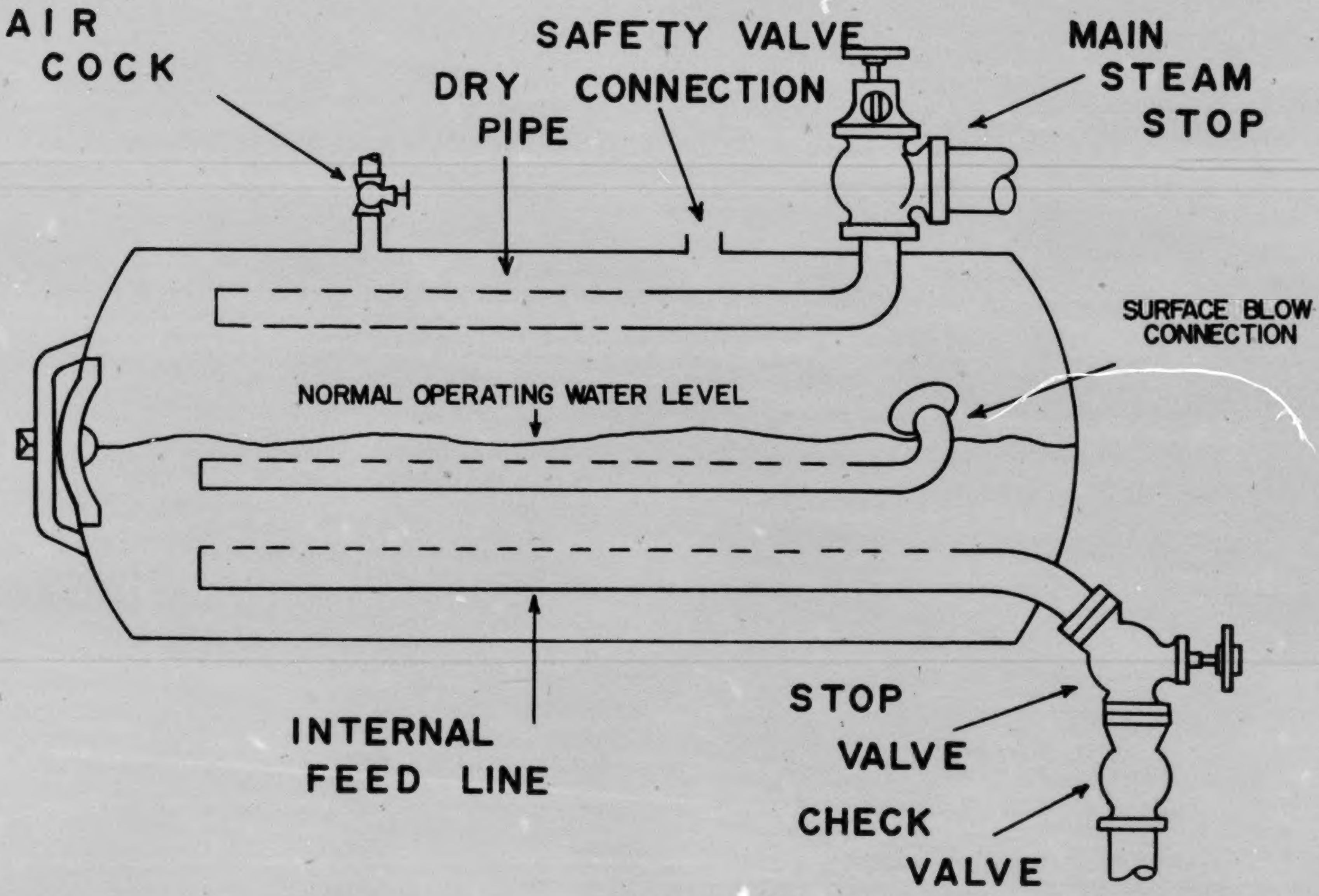
When the boiler is off the line for inspection, the internal feed line should be carefully examined to make sure that it is secure and that there are no plugged holes.

References:

Elementary Steam Power Engineering
A.S.M.E. Code, Section I
Steam Plant Operation

Assignment:

1. How must the internal feed water lines be introduced into the boiler?
2. Why is the above so important?
3. What are the Code requirements for feed water inlets when pressures are 400 pounds or over?
4. How far into the drum do feed lines go in a watertube boiler?
5. Discuss the Code requirements or internal feed lines for H.R.T. boilers.
6. What care should be given internal feed lines during inspection?


AIR COCK
SAFETY VALVE
DRY PIPE
CONNECTION
MAIN STEAM STOP
SURFACE BLOW CONNECTION
NORMAL OPERATING WATER LEVEL
INTERNAL FEED LINE
STOP VALVE
CHECK VALVE

STEAM AND WATER DRUM

4-E-1-1

Soot Blowers: Function and Use

Assignment 4-F-1

Objectives:

1. Be able to explain function of soot blowers.
2. Be able to use soot blowers.

Information: In order to have a transfer of heat, there must be a difference in temperature between two substances. The greater this differance is, then the greater the heat transfer will be.

Soot is carbon and carbon is unburned fuel. It acts as an insulator when left on the heating surface of a boiler. Removal of the carbon allows a better heat transfer.

In a firetube boiler, the gases of combustion pass through the tubes to remove the soot deposits. It is necessary to take the boiler off the line and use brushes or scrapers to remove the soot. Soot blowers are not very effective in firetube boilers, but you may find them on some of the older H.R.T. boilers.

In watertube boilers, the gases of combustion pass around the tubes. The soot deposits can be easily removed by using soot blowers. Most modern watertube boilers will be equipped with permanently installed soot blowers.

Soot blower elements are located in the direct path of the gases of combustion. They must be made of a steel alloy to withstand the high temperatures of the flue gases. The nozzles in the element are spaced so that they will allow steam or air to blow between the rows of tubes. They are held in place by bearings that are clamped or welded to the boiler tubes. The bearings allow the element to rotate.

Element alignment is important. If the element were to shift, steam impinging on the boiler tubes would actually cut through the boiler tube in a very short period of time. The element is connected to a cam-operated valve in the head of the soot blower. It is chain operated. As it rotates the element, the steam valve is open at the proper time allowing steam to blow through the nozzles. As it is rotated further, it will close the steam valve when the arc of soot blowing is completed.

The steam line feeding the soot blowers must come from the highest part of the steam side of the boiler to insure moisture free steam. It is important that the soot blower lines be thoroughly warmed up and completely drained. Any water that would be discharged with the steam would cause the soot to cake up, and the sulfur in the soot mixing with the water would cause damage to the boiler heating surface.

To blow tubes, it is necessary to warm up and drain the lines, increase boiler draft, and follow boiler manufacturer's instructions on which elements to blow first. Usually you will follow the path of the gases starting with the first pass to the last pass.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Why do you think soot blowers would not be very effective in firetube boilers?
2. What is soot composed of?
3. Why is element alignment so important in soot blowers?
4. What effect will water mixed with steam have when blowing tubes?
5. Where does the steam line feeding the soot blowers come from? Why?
6. List procedure to follow when blowing tubes.

Objective: Be able to locate the explain the purpose of all the equipment found in a feed-water system.

Information: A fireman must know of every possible way of getting water to his boilers. A steaming boiler can, in a matter of minutes, have the water in the gage glass go from half of a glass to an emply glass. A boiler that is on the line and loses its water could burn up or possibly explode causing damage and loss of life. It takes one pound of water to make one pound of steam. If your boiler is generating 20,000 pounds of steam per hour, you must supply it with 20,000 pounds of water per hour. Water weighs approximately 8.3 pounds per gallon, so that boiler will need about 2410 gallons of water per hour. This should give you some idea of the importance of your feed-water system and why it is necessary to know the purpose and location of all its parts.

Let's look at Figure 5-A-1-1 for a sketch of a feed-water system.

The returns from the system (1) enter the open feed water heater (2). Oxygen and other non-condensable gases are vented to the atmosphere (3). All the steam does not return to the feed water heater as condensate; some is lost due to leaks or process. A float (4) opens a valve (5) located on a city water line (6) to add make-up water. To prevent the feed-water heater from becoming water logged, there is an internal over-flow line (7) which will discharge to waste (8). The feed-water heater is located above the feed-water pumps, so the water is supplied to the pumps through the suction line (9) at a slight head pressure. The feed-water pump (10) is an electric centrifugal pump and the second feed-water pump (11) is a steam driven turbine centrifugal pump. This allows the plant to be more flexible. Each feed-water pump will have its own set of suction valves (12) and discharge valves (13). This would allow either pump to be taken out of service for repairs. Each feed water pump will also have its own check valve (14) to prevent water from backing up if the check valve (31) located close to the boiler should fail. The feed water leaves the pump through a discharge line (15) and enters the closed feed water (16) where it is heated to a relatively high temperature. The closed feed-water heater is equipped with an inlet valve (17) and an outlet valve (18); it is also necessary to have a by-pass line and valve (19), so that the heater can be taken out of service without a shutdown.

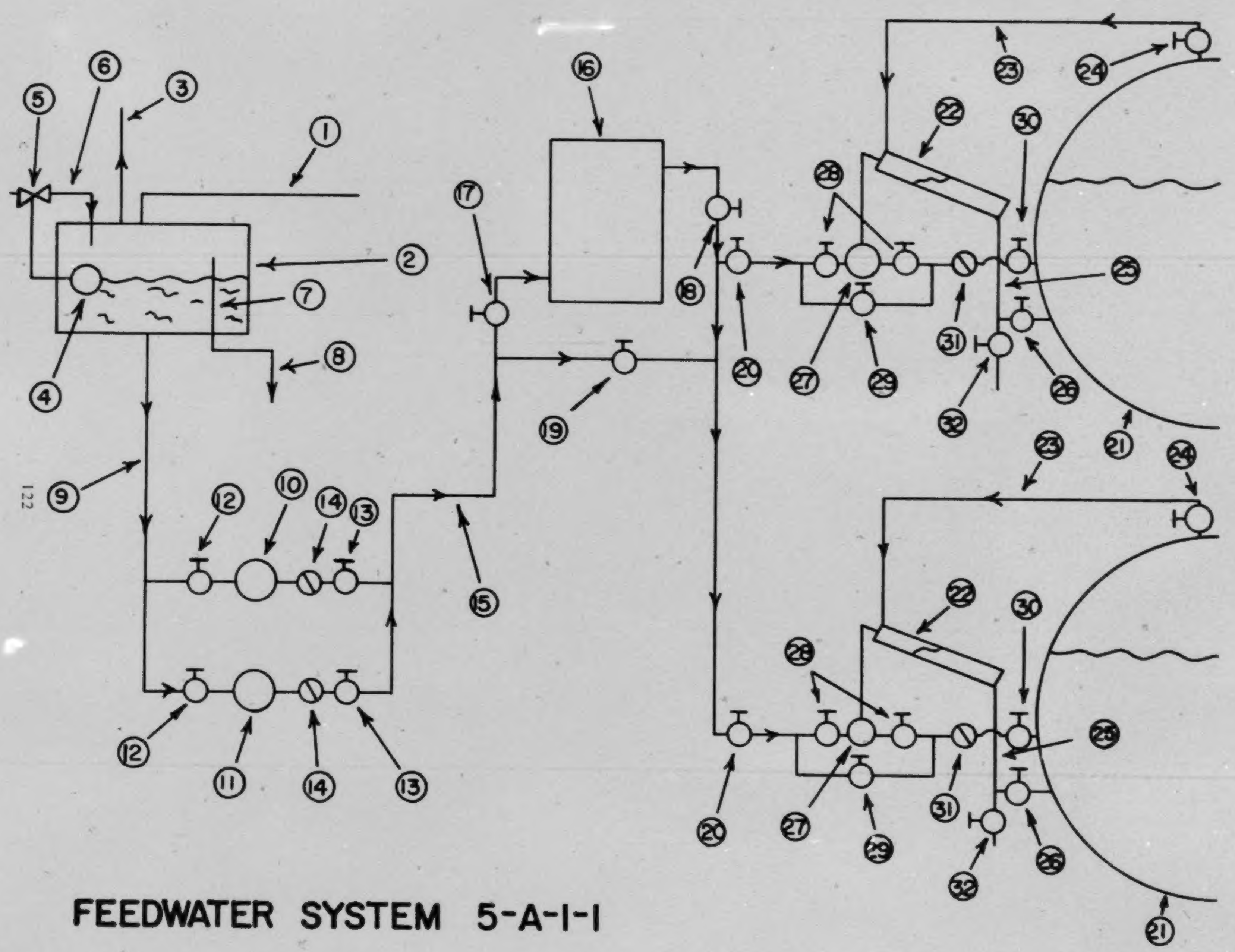
After the closed feed-water heater, the main feed-water line has branch lines, one for each boiler in the plant. Each branch line has a main feed-water stop valve (20). In order to maintain a proper level in each boiler (21), an automatic feed-water regulator is used. It can be the thermal-expansion or the thermal-hydraulic type. The control element (22) is located at the normal operating water level. The top of the control element is connected by a line (23) that goes to the highest part of the steam side of the boiler. There is a shut-off valve (24), so that the regulator may be taken out of service for repairs. The bottom of the element is connected to the boiler by a line (25) that is well below the normal operating water level. The shut-off valve (26) is also used when making repairs. The element is connected to a regulating valve (27) located in the feed-water line (15). The feed-water regulating valve (27) has two shutoff valves (28) so that the regulator may be taken out of service if it fouls up. The water would then go through the bypass valve (29). This would prevent taking a boiler off the line because of a regulator failure. On the feed-water line, you will notice a stop valve (30) and a check valve (31). The stop valve is located closest to the shell of the boiler so that the check valve (31) could be repaired without dumping the boiler. The feed-water regulator is equipped with a blowdown valve (32) to insure that the water and steam lines are free and clear of sludge and sediment.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Procedure: After studying the information and references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Name all the equipment that is found in a feed-water system.
2. State the purpose and location of each piece of equipment in the system.
3. Why is makeup water needed? How is it added to the system?
4. Why is the stop valve placed in the feed-water line closest to the shell of the boiler?
5. What prevents water from backing up into the return lines?
6. If the feed-water regulator failed, how would you get water to your boiler?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FEEDWATER SYSTEM 5-A-1-1

Objective: Be able to locate and to explain the purpose of all the equipment found in a No. 6 fuel oil system.

Information: The purpose of any fuel oil system is to get the fuel oil to the burner at the proper temperature and pressure. This means that we must pump, heat, and regulate the flow of fuel oil before it reaches the burner. Once the fuel oil gets to the burner, it is the burner's function to properly distribute the fuel into the combustion chamber of the boiler.

The fuel oil system in Figure 5-B-1-1 consists of various parts. We will start with the storage tanks (1). Most steam plants that use No. 6 oil will have two tanks; the size of the tanks will depend on the number of gallons that a plant will burn in an average day. In order to pump No. 6 fuel oil, it has to be heated. This is accomplished by a heating bell or coil located in the fuel oil tank and controlled by a steam regulator (2). To give us an indication of the temperature of the oil coming from the tank, there is a thermometer (3) located on the suction line. There are stop valves (4) to isolate a tank when it is not in use. The duplex strainers (5) permit one strainer to be cleaned while the other is in service. The suction gage (6) shows how much pressure is on the suction side of the pump.

The suction valves (7) and discharge valves (8) located before and after the fuel oil pumps allow you to isolate a pump from the system. The fuel oil pumps (9) increase the pressure while moving the fuel oil through the discharge line (10). It is a good practice to have an electrically-driven and a steam-driven fuel oil pump in the system in case of a power failure.

The relief valves (11) protect the system from excessive oil pressure and discharge back to the fuel oil return line (12). A pressure gage (13) indicates the fuel oil discharge pressure. The fuel oil is further heated by a steam fuel oil heater (14). Inlet valves (15) and outlet valves (16) allow you to isolate a heater for maintenance.

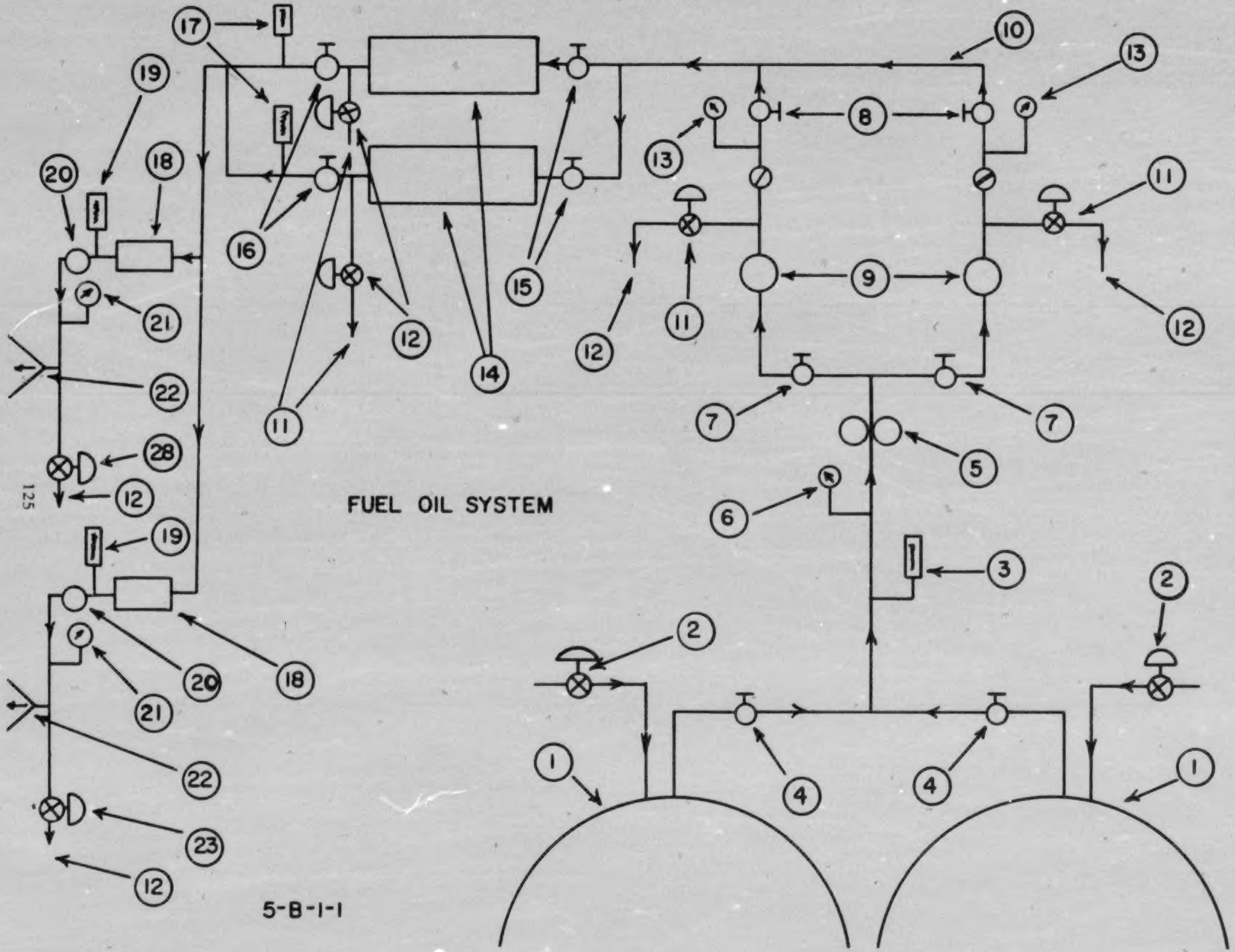
A thermometer (17) indicates the temperature of the oil leaving the heater. The oil then goes to an electric heater (18) where the oil is brought up to the temperature at which it is to be burned. A thermometer (19) shows the temperature of the oil after it leaves the electric heater.

A simplex strainer (20) is used to collect any impurities or dirt left in the oil. A pressure gage (21) indicates the pressure of the oil at the burner (22) which is regulated by a back pressure valve (23). All of the oil is not burned. Some oil is recirculated through a return line (12). A thermometer shows the oil return temperature as the oil is returned to the storage tank.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Name all of the parts in a fuel oil system.
2. State the purpose and the location of each piece of equipment in the system.
3. Why are relief valves needed in the system?
4. What controls the pressure in the system?
5. Why does the oil have to be heated in the storage tank?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5-B-1-1

FUEL OIL SYSTEM

Objectives:

1. Be able to calibrate a fuel oil tank.
2. Be able to compute fuel oil readings.
3. Be able to compute fuel oil consumption.

Information: The fireman and engineer is responsible for the maintaining of boiler room records and readings. He must be able to figure fuel oil consumption and keep records of all oil used per hour, per day, per week, or per year.

Fuel oil tanks may be equipped with a fuel gage which will give you the gallons of oil in the tank. If a gage is not installed or if it is faulty you must be able to sound the tank and figure the oil it contains from a chart. When you sound the tank you will get a reading in feet and inches. Looking at sketch VII-B-2-1 it should be clear that 1" of oil at point "A" would not be the same number of gallons as at point "B" or at point "C".

Example: Stick sounding Monday – 5′6″
Tuesday – 5′2½″

Find:
1. Oil in tank Monday
2. Oil in tank Tuesday
3. Oil consumed

Monday Reading:
Change feet to inches
5 X 12 = 60″
60 + 6 = 66″
Using the chart for tank, 66″ = 10,648 gals.

Tuesday Reading:
Change feet to inches
5 X 12 = 60″
60 + 2½ = 62½″

Note: There is no reading on the tank chart for ½″ of oil. It will be necessary to interpolate:

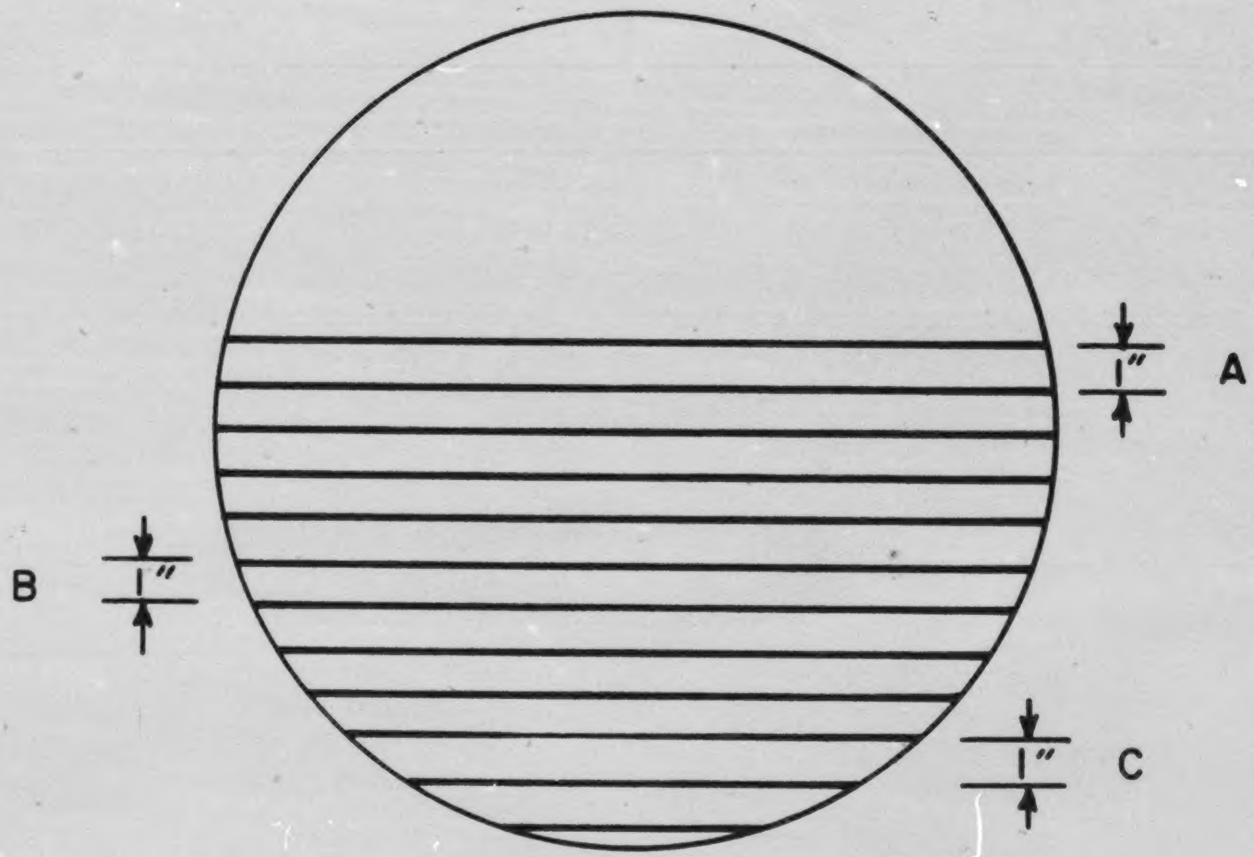
Find gals. 63″ = 10,040
Find gals. 62″ = 9,837
Subtract 203 gals. per inch
Take ½ = 101.5 gals. per ½″
Gals. at 62″ = 9,837
Add + 101.5
Gals. at 62½″ = 9,938.5
Add + 101.5
Gals. at 63″ = 10,040.0

Oil reading Monday	10,648
Oil reading Tuesday	- 9,938
Oil used	710 gals.

1.	Oil in tank Monday	10,648 gals.
2.	Oil in tank Tuesday	9,938 gals.
3.	Oil used	710 gals.

Assignment: Using the following fuel oil chart find the gallons of oil for the following readings:

1. Stick sounding – 4′4½″. How much oil is in the tank?
2. Stick sounding: Friday 8 A.M. – 6′8″
   Monday 8 A.M. – 5′3″
   Find: a. total gals. burned
   b. gals burned per day
3. Stick sounding: Monday – 3′3½″, received oil delivery – reading after drop 6′8″.
   Find: gallons of oil delivered
4. Stick sounding: 9/1 Monday 8 A.M. – 8′6″
   9/2 Tuesday 8 A.M. – 8′2½″
   9/3 Wednesday 8 A.M. – 7′11″
   9/4 Thursday 8 A.M. – 7′4½″
   9/5 Friday 8 A.M. – 6′6″
   9/8 Monday 8 A.M. – 4′10½″
   Find: a. fuel burned daily from 9/1 to 9/5
   b. fuel burned 9/5 to 9/8 (total)
   c. fuel burned per day 9/5 and 9/8
   d. total gallons consumed from 9/1 to 9/8
5. Find ten ½″ readings that will be given to you by your instructor.
6. A complete ½″ calibration chart will be made by each student in class using the calculations obtained in No. 5.



Tank sketch showing 1" of oil

5-B-1-M1-1

Calibration Chart Tank #1

Inches	Gallons	Inches	Gallons	Inches	Gallons
1	26	41	6039	81	14446
2	72	42	6241	82	14647
3	131	43	6446	83	14844
4	201	44	6641	84	15041
5	281	45	6858	85	15236
6	368	46	7066	86	15428
7	463	47	7275	87	15620
8	565	48	7485	88	15810
9	672	49	7694	89	15997
10	787	50	7904	90	16183
11	906	51	8116	91	16367
12	1030	52	8350	92	16548
13	1159	53	8542	93	16727
14	1292	54	8756	94	16904
15	1431	55	8978	95	17077
16	1572	56	9181	96	17249
17	1718	57	9395	97	17417
18	1868	58	9610	98	17583
19	2021	59	9825	99	17745
20	2177	60	10038	100	17906
21	2337	61	10253	101	18058
22	2500	62	10468	102	18210
23	2665	63	10681	103	18359
24	2833	64	10896	104	18507
25	3004	65	11108	105	18647
26	3178	66	11322	106	18785
27	3354	67	11540	107	18920
28	3533	68	11752	108	19047
29	3715	69	11964	109	19172
30	3898	70	12176	110	19291
31	4085	71	12386	111	19404
32	4272	72	12597	112	19512
33	4462	73	12807	113	19614
34	4652	74	13015	114	19708
35	4846	75	13223	115	19799
36	5041	76	13430	116	19875
37	5236	77	13635	117	19945
38	5435	78	13841	118	20005
39	5634	79	14044	119	20052
40	5836	80	14257	120	20078

20,000 gallon tank 10′ dia., 34′ 3″ long flat heads

Objective: Be able to correct No. 6 fuel oil to the standard 60°F.

Information: Bunker C or No. 6 oil is used in industry and in marine work as a major source of fuel. It has a very high B.t.u. content. It may vary from 148,000 to 152,000 B.t.u.'s per gal. It not only must be heated to burn, but it must also be heated to make pumping easy. It is delivered in *BULK* either by truck, train, or barge. Now, if a liquid is heated, what happens to its volume? Does it increase or decrease? If it does increase, by how much? If the oil is heated to 200°F. and then cools in the tank after delivery to 100°F., am I getting a fair deal? How much oil did I get, and how much oil did I pay for?

You can see that there would be many problems unless a standard could be set up. It was decided that regardless of what the temperature was when the oil was delivered, it would be converted to 60°F to determine the number of gallons that you would be billed for.

In order to correct No. 6 fuel oil to 60°F, the following equation can be used.

$$\text{Corrected gallons} = \text{Gallons delivered}\left[1.0000 - (.000345\,[\text{Temp} - 60^\circ\text{F}])\right]$$

The corrected number of gallons can be found by four simple steps:

Step 1: Temperature of Oil Delivered − 60°F.
Step 2: Step 1 × .000345
Step 3: 1.000 − Step 2
Step 4: Step 3 × Gallons of Oil Delivered = Corrected Gallons

Example: A steam plant received 5415 gallons of fuel oil at 130°F. How many gallons would that be when corrected to 60°F?

Step 1: Temperature of Oil Delivered − 60°F =
130 − 60 = 70

Step 2: Step 1 × .000345 =
70 × .000345 = .024150

Step 3: 1.0000 - Step 2 =
1.0000 - .02415 = .97585

Step 4: Step 3 × Gals of Oil Delivered = Corrected Gals.
.97585 × 5415 = 5284 gals. at 60°F.

Assignment: 1. Correct the following oil deliveries to 60°F:

	Gallons Received	Temp of Oil
a.	4725	120°
b.	5117	130°
c.	5129	120°
d.	5155	140°
e.	5249	130°

2. Find the constant (Step 3 in figuring corrected gallons) for the following temperatures:

   a. 120°
   b. 125°
   c. 130°
   d. 135°
   e. 140°
   f. 145°

Objectives:

1. Be able to describe the various gas burner systems.
2. Be able to identify the parts and to explain the function of each part in the different gas systems.

Information: The pressure of the gas available at your plant will play an important part in the type of system that you will have.

The first system we will discuss will be a low-pressure gas system. In this system the gas supplied at the burner is reduced to 0 (zero) pounds pressure. The gas and primary air mix together outside the combustion chamber and are forced along to the gas nozzle by a blower. Using Figure 5-B-2-1, let's trace the system: The gas line (1) is fitted with a gas cock (2) which allows the fireman to close the gas from the system when making repairs. The solenoid valve (3) controls gas to the pilot (4). The manual reset valve (5) is an electric valve that cannot be opened until the gas pilot is lighted. The pressure reducing governor (6) reduces the pressure of the gas to zero pounds pressure. The small line just before the pressure reducing governor goes to the vaporstat (7). The vaporstat is a switch which is turned on by the gas pressure in the line or turned off when there is no pressure. The main gas solenoid valve (8) will open at the proper time allowing gas to be drawn down to the mixjecter (9). The forced draft blower (10) will send air through the butterfly valve (11). The air passes through a venturi (12) and draws the gas with it to the mixing chamber (13).

The block and holder (14) is mounted on the boiler front and as the gas and air mixture passes through the cage, it is ignited by the pilot light (4). The cage has an adjustable ring (15) that controls the secondary air that enters to complete combustion. A gas cock (16) controls the gas flow to the pilot.

The High-Pressure Gas Burner System supplies gas at a set pressure to the burner, where it mixes with the air on the inside of the burner register. Using Figure 5-B-2-2 let's trace the high pressure system.

The gas line (1) is fitted with a pressure gage (2) and a manually operated shut-off valve (3). A gas pressure regulator (4) controls the desired set pressure at the burner. The electrically operated solenoid valve (5) is used as an automatic shut-off gas valve. A gas control flow valve (6) gradually allows the gas to flow to the burner at start-up. A gas volume control valve (butterfly valve) (7) controls the volume of gas to the burner. A gas pilot line (8) supplies gas to the gas pilot regulator (9), a gas pressure gage, (13) and an electrically operated solenoid valve (10). Air is supplied by a forced draft blower (11) and mixes with the gas in the burner register (12) where ignition occurs.

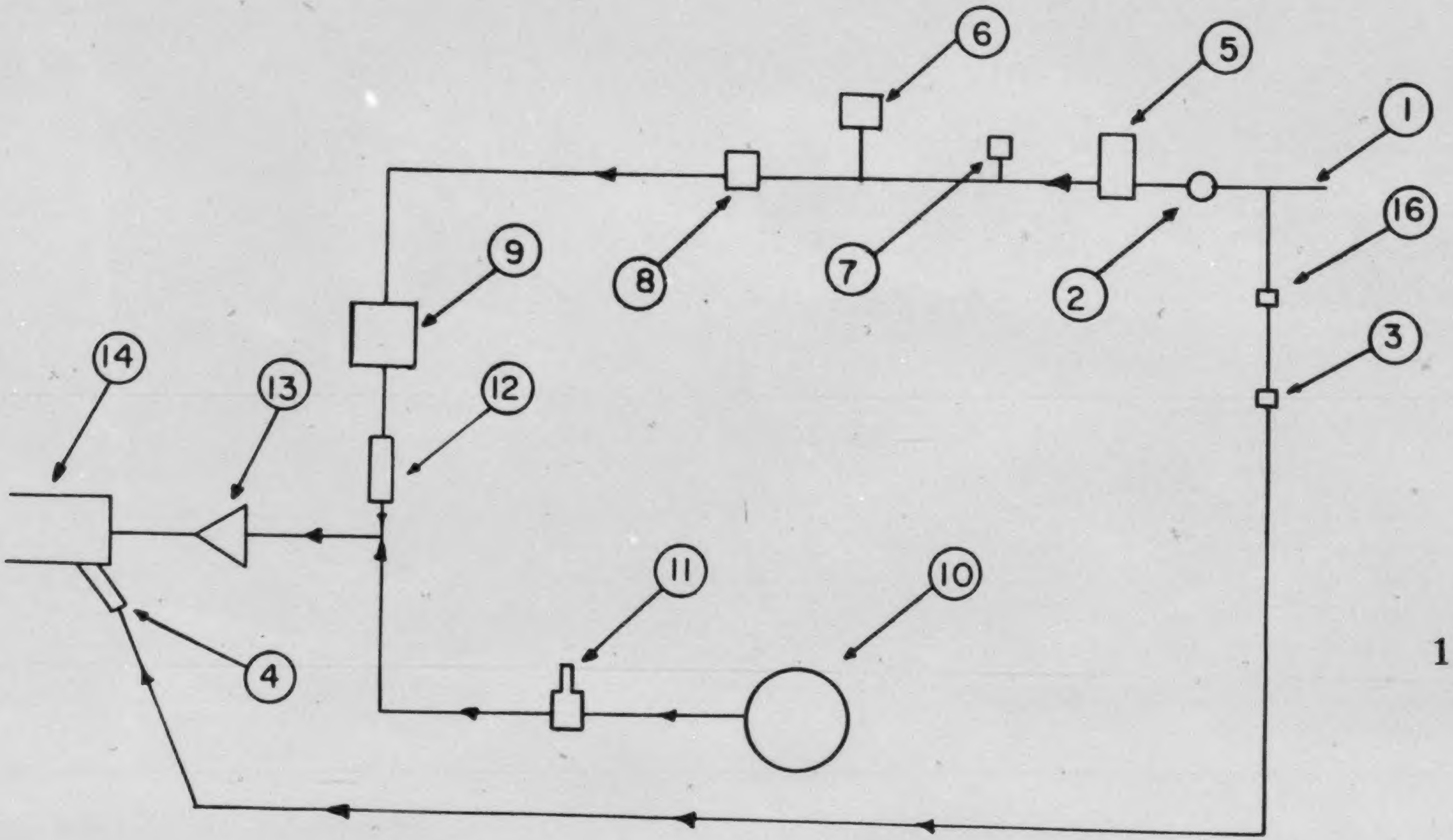
In some installations, combination burners are used. These burners are actually two burners in one and are capable of burning gas or oil. This is very important when a shut-down due to lack of fuel could be expensive. There is also the advantage of burning the cheapest fuel at any given time. With the air pollution laws becoming more strict it may be necessary to burn gas only.

A combination oil-gas burner is basically the same as having an oil burner and a gas burner system connected together at the burner throat (at the front of the furnace). The parts of the system are the same as if they were separate. See figures, 5-B-2-4, 5-B-2-5, 5-B-2-6 and 5-B-2-7.

As you can see, the sketches show a High-Pressure Gas System. It operates like the one described earlier in our lesson. The one exception is the sketch 5-B-2-7 which shows a vent line. It is installed for safety so that gas from a faulty main valve cannot leak into the surrounding area.

Assignment:

1. Describe how a low pressure gas system operates.
2. Describe how a high-pressure gas system operates.
3. What safety devices are installed in each system?
4. Where is the venturi used?
5. Describe a combination gas-oil burner.
6. Why are many plants converting to combination gas-oil burners?
7. Why are vent lines installed?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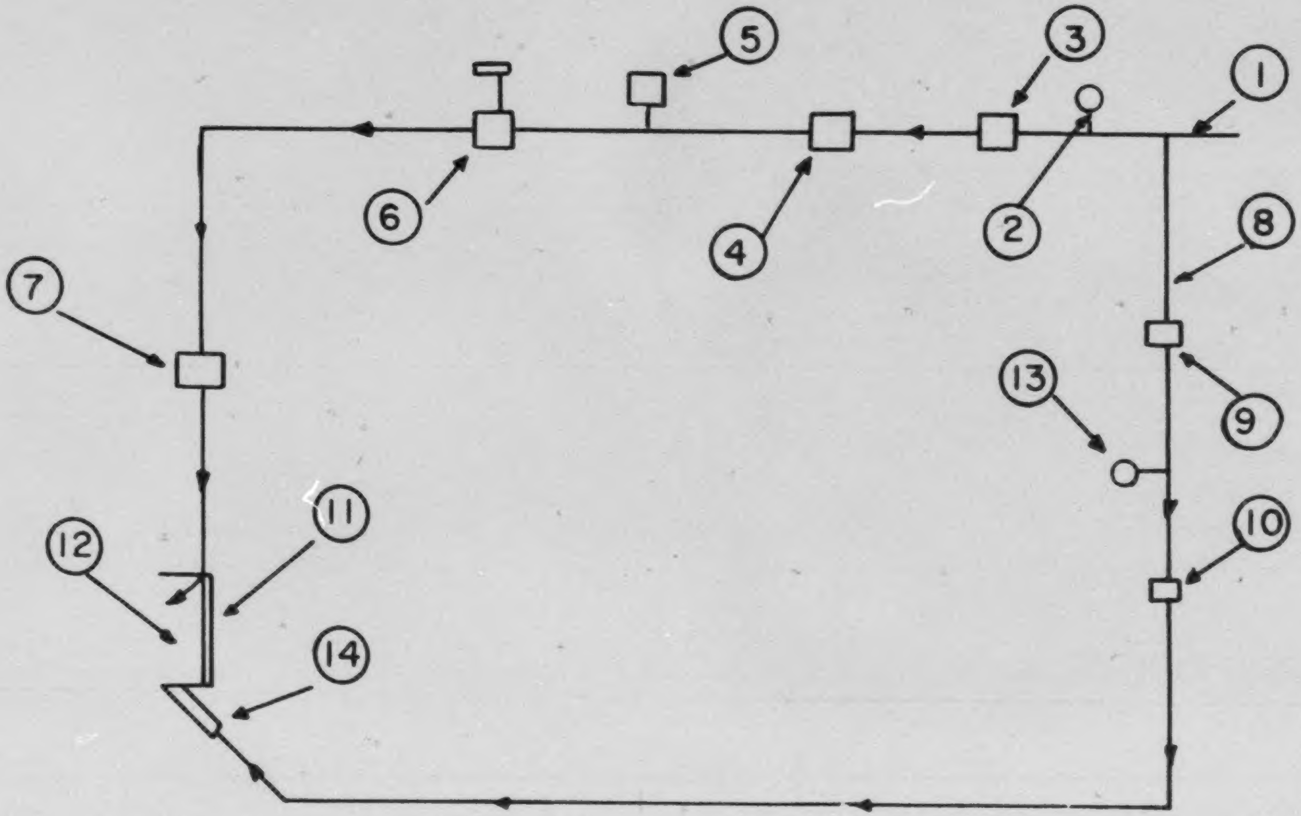
BASIC H. P. GAS BURNER SYSTEM

5-B-2-1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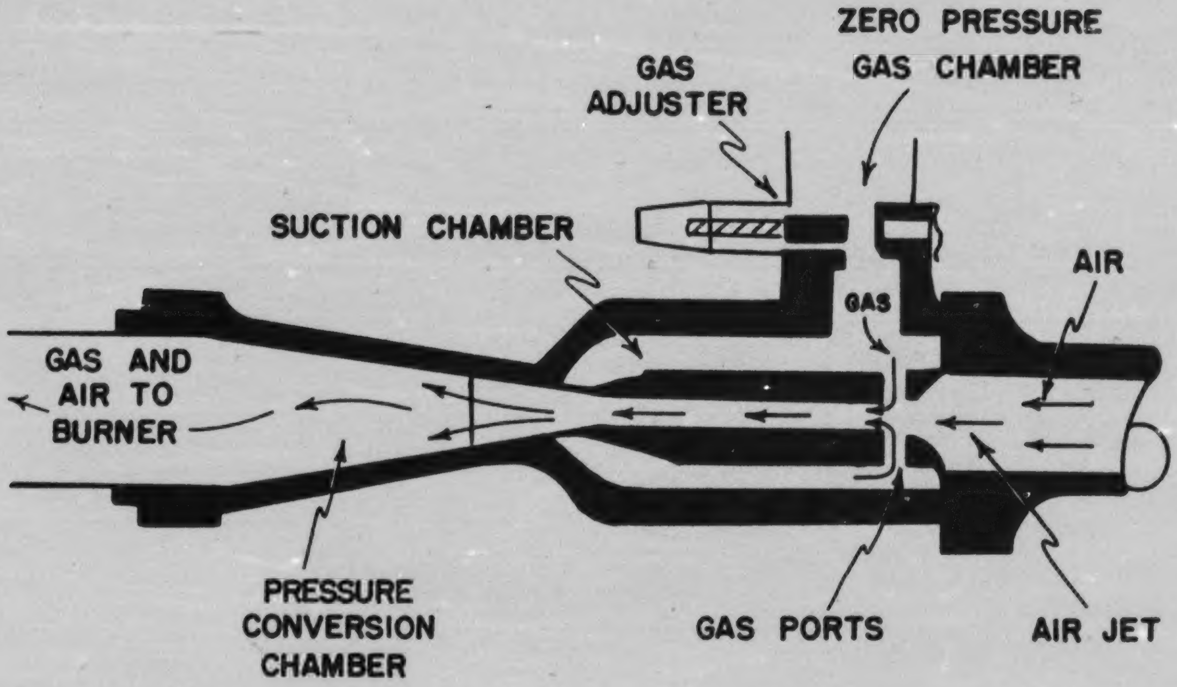
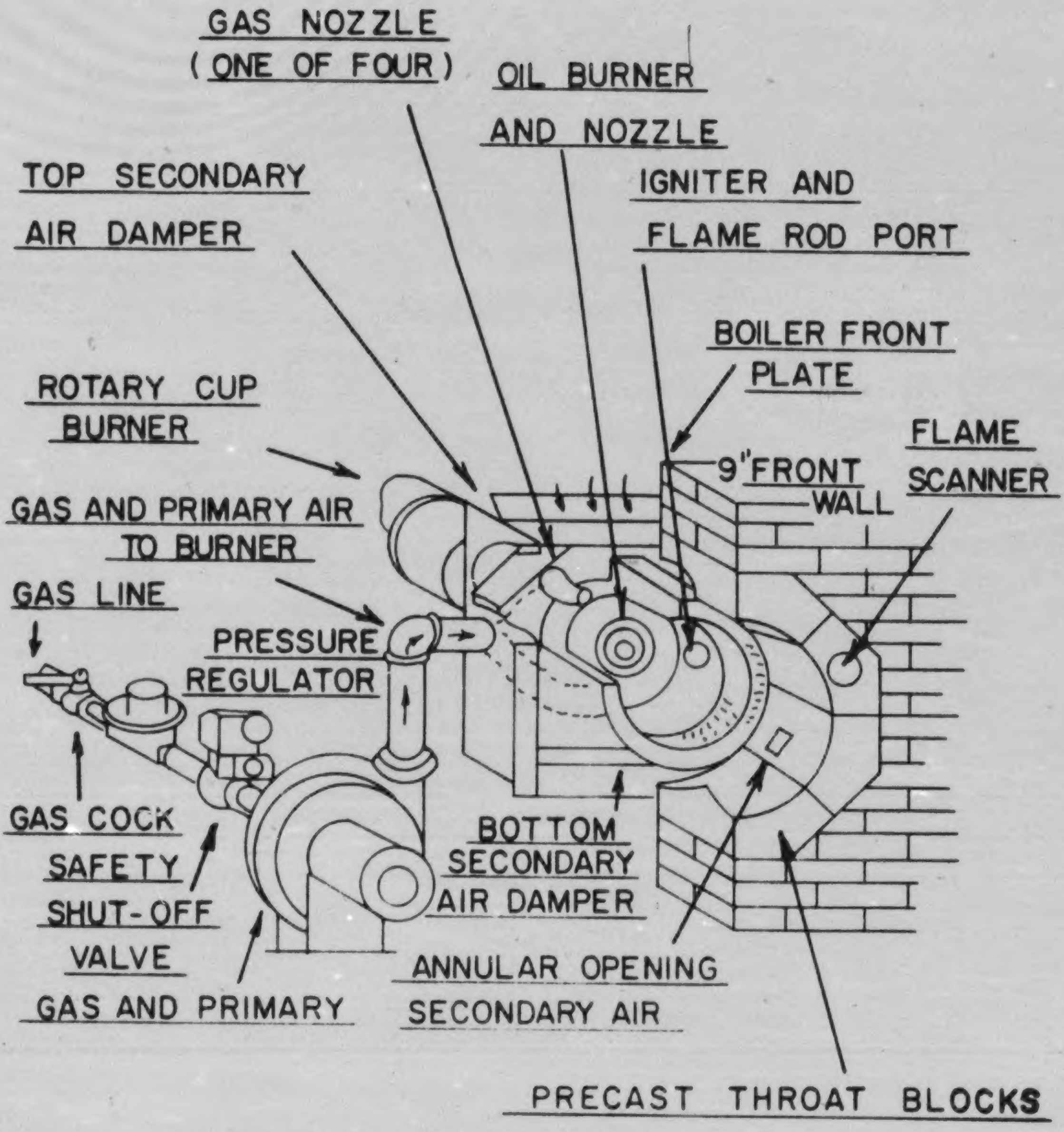
BASIC H. P. GAS BURNER SYSTEM

5-B-2-2


ZERO PRESSURE GAS CHAMBER
GAS ADJUSTER
SUCTION CHAMBER
AIR
GAS
GAS AND AIR TO BURNER
PRESSURE CONVERSION CHAMBER
GAS PORTS
AIR JET

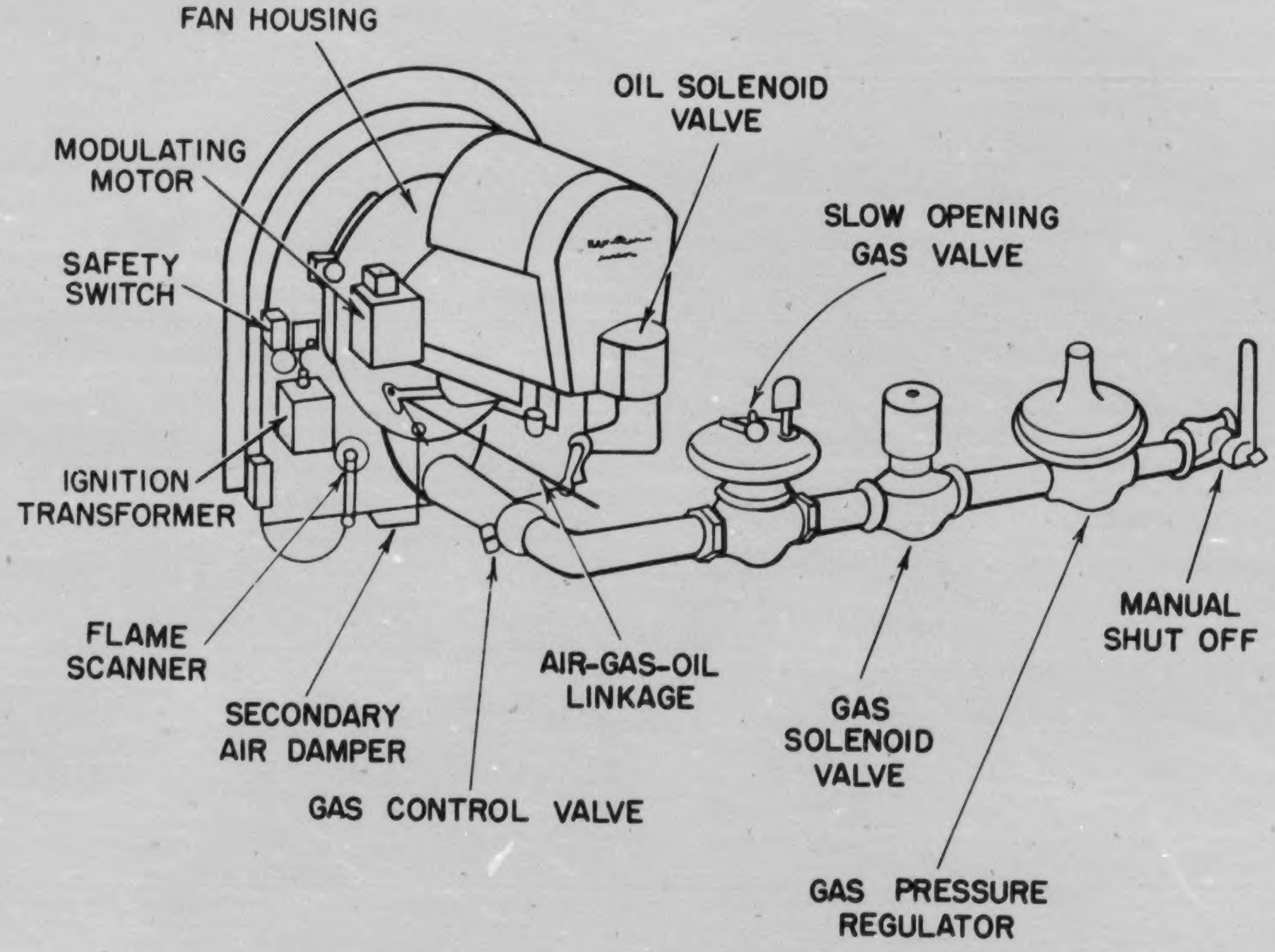
BRYANT FLOMIXER

5-B-2-3


GAS NOZZLE (ONE OF FOUR)
OIL BURNER AND NOZZLE
TOP SECONDARY AIR DAMPER
IGNITER AND FLAME ROD PORT
BOILER FRONT PLATE
ROTARY CUP BURNER
FLAME SCANNER
9" FRONT WALL
GAS AND PRIMARY AIR TO BURNER
GAS LINE
PRESSURE REGULATOR
GAS COCK
SAFETY SHUT-OFF VALVE
BOTTOM SECONDARY AIR DAMPER
GAS AND PRIMARY
ANNULAR OPENING SECONDARY AIR
PRECAST THROAT BLOCKS

SCHEMATIC VIEW COMBINATION GAS AND OIL BURNER FROM INSIDE FURNACE

5-B-2-4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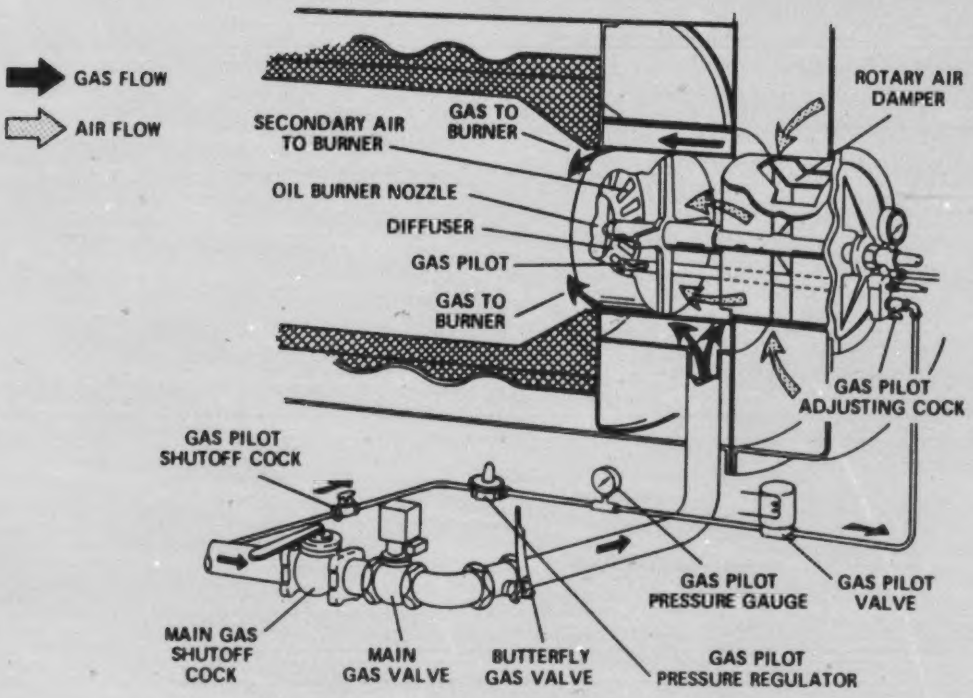
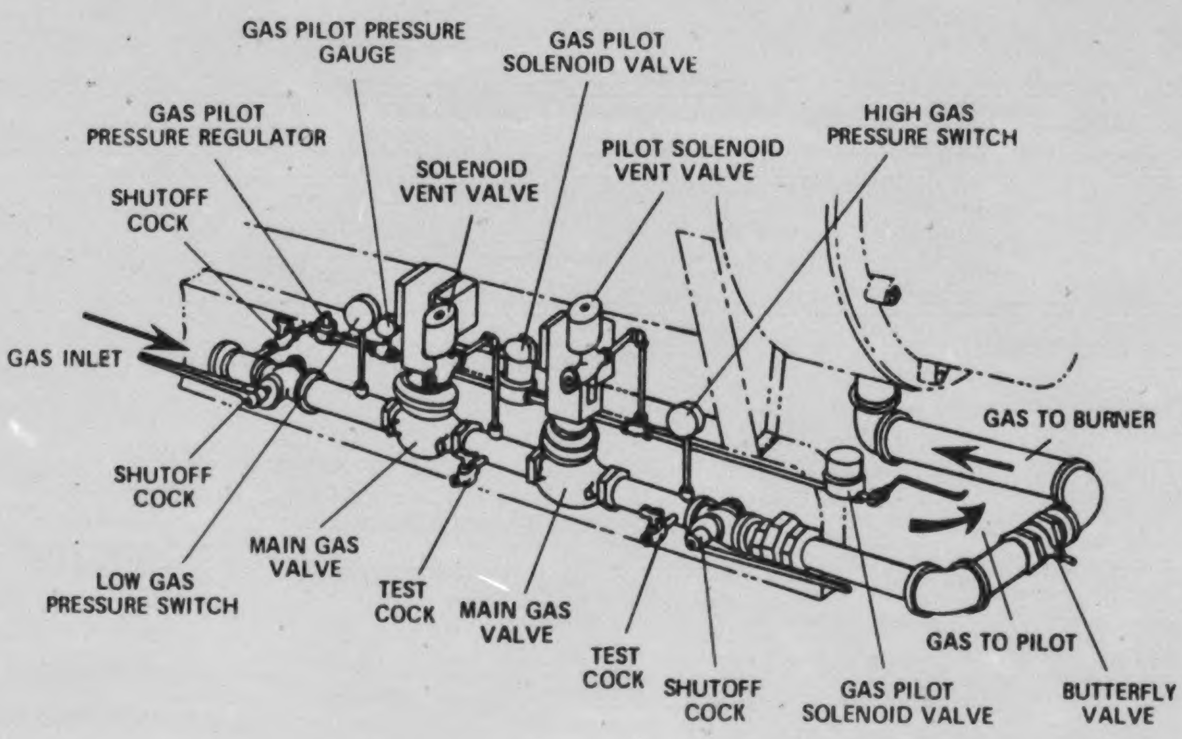
OIL SOLENOID VALVE
MODULATING MOTOR
SLOW OPENING GAS VALVE
SAFETY SWITCH
IGNITION TRANSFORMER
FLAME SCANNER
SECONDARY AIR DAMPER
GAS CONTROL VALVE
AIR-GAS-OIL LINKAGE
GAS SOLENOID VALVE
GAS PRESSURE REGULATOR
MANUAL SHUT OFF

COMBINATION GAS-OIL BURNER

5-B-2-5


GAS FLOW
AIR FLOW
ROTARY AIR DAMPER
GAS TO BURNER
SECONDARY AIR TO BURNER
OIL BURNER NOZZLE
DIFFUSER
GAS PILOT
GAS TO BURNER
GAS PILOT ADJUSTING COCK
GAS PILOT SHUTOFF COCK
GAS PILOT PRESSURE GAUGE
GAS PILOT VALVE
MAIN GAS SHUTOFF COCK
MAIN GAS VALVE
BUTTERFLY GAS VALVE
GAS PILOT PRESSURE REGULATOR

5-B-2-6


GAS PILOT PRESSURE GAUGE
GAS PILOT SOLENOID VALVE
GAS PILOT PRESSURE REGULATOR
HIGH GAS PRESSURE SWITCH
SOLENOID VENT VALVE
PILOT SOLENOID VENT VALVE
SHUTOFF COCK
GAS INLET
GAS TO BURNER
SHUTOFF COCK
MAIN GAS VALVE
LOW GAS PRESSURE SWITCH
TEST COCK
MAIN GAS VALVE
GAS TO PILOT
TEST COCK
SHUTOFF COCK
GAS PILOT SOLENOID VALVE
BUTTERFLY VALVE

5-B-2-7

Objectives:

1. Define draft.
2. Be able to explain why it is necessary to control draft in a boiler.
3. Be able to control draft in a boiler.

Information: Draft has been defined as a difference in pressure which will cause air to flow. In order to burn a fuel completely in a furnace, it is necessary to have sufficient quantities of air under the correct pressure to overcome all resistance encountered as it passes through the boiler. Draft is classified as natural or mechanical.

Natural draft is produced only by a chimney. The hot gasses inside the chimney rise and are replaced by the cooler air outside the chimney. The amount of draft is dependent upon the difference in temperature of the column of gas inside the chimney as compared with a column of air outside the chimney.

Mechanical draft is produced by power driven fans. The two types of mechanical draft are forced and induced. Forced draft is produced when the fan or blower is forcing the air into the furnace. Induced draft is produced when the fan or blower is removing gasses of combustion from the boiler and discharging them into the chimney. Forced and induced draft fans are used in combination on large boiler installations.

In order that the correct fuel-air ratios can be maintained for good, clean, efficient combustion, it is necessary to control the draft through a boiler at all times even under changing load conditions. Draft can be controlled by:

1. speed of the induced or forced draft fans.
2. use of dampers
3. use of inlet vanes on the fan.

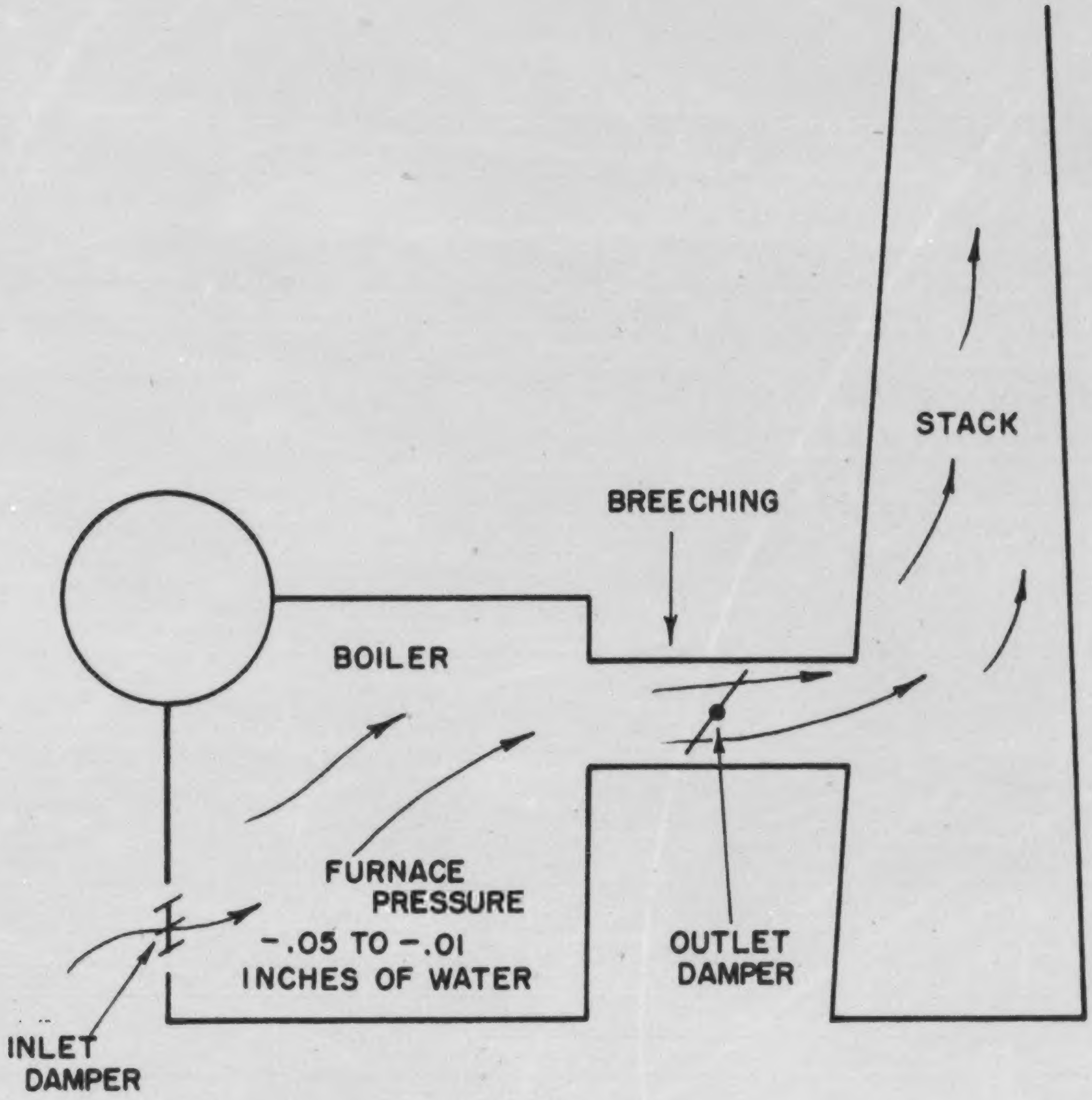
On natural draft boilers, the draft is controlled by an outlet damper located after the last pass of the boiler and an inlet damper before the furnace. The outlet damper moves toward the open or closed position to maintain a constant furnace pressure of .05 to .1 inches of water below the atmospheric pressure. The inlet damper opens or closes to allow the proper amount of air for the amount of fuel being used (fuel-air ratio). On forced and induced draft boilers, there will be inlet and outlet dampers, and the fan speed can be increased or decreased depending on load conditions to control the correct amount of draft.

Inlet vanes on forced draft fans are used on constant speed fans to control inlet air to the furnace. When the pressure within the furnace is kept constant, it is called a balanced draft system.

References: *Steam Plant Operation*
Elementary Steam Plant Engineering

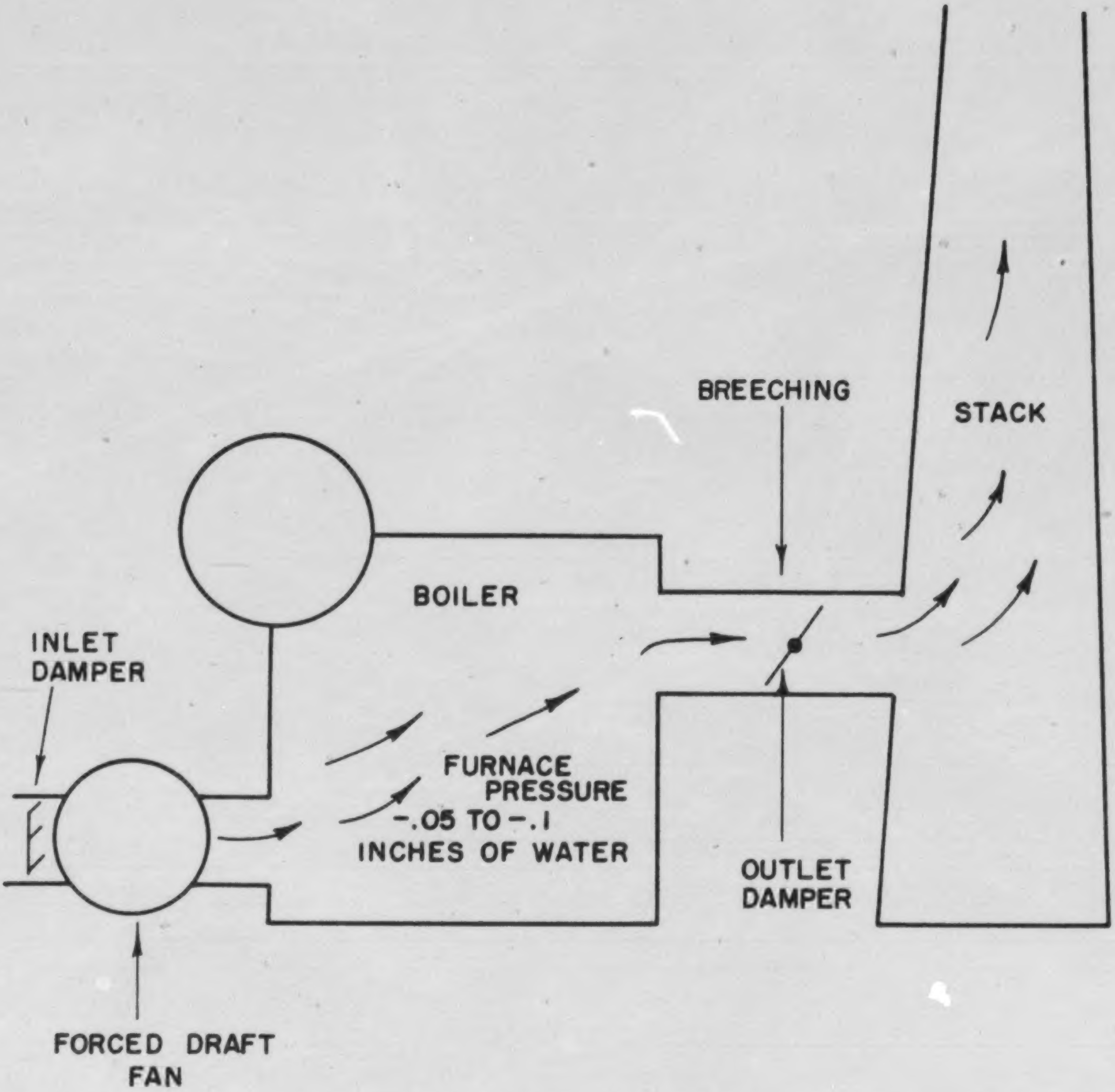
Assignment:

1. Define draft. How is it measured?
2. Define the types of draft found on boilers used in industry.
3. What is the function of a chimney?
4. How is draft controlled?
5. Explain "balanced draft."
6. What are the advantages of mechanical draft over natural draft?
7. Why is it necessary that draft be carefully controlled?
8. If you were having trouble carrying a load on a boiler, how would you determine if insufficient draft was the cause?
9. What are the conditions that make mechanical draft necessary?
10. What are some of the difficulties that can be encountered when operating fans?


STACK
BREECHING
BOILER
FURNACE
PRESSURE
-.05 TO -.01
INCHES OF WATER
OUTLET
DAMPER
INLET
DAMPER

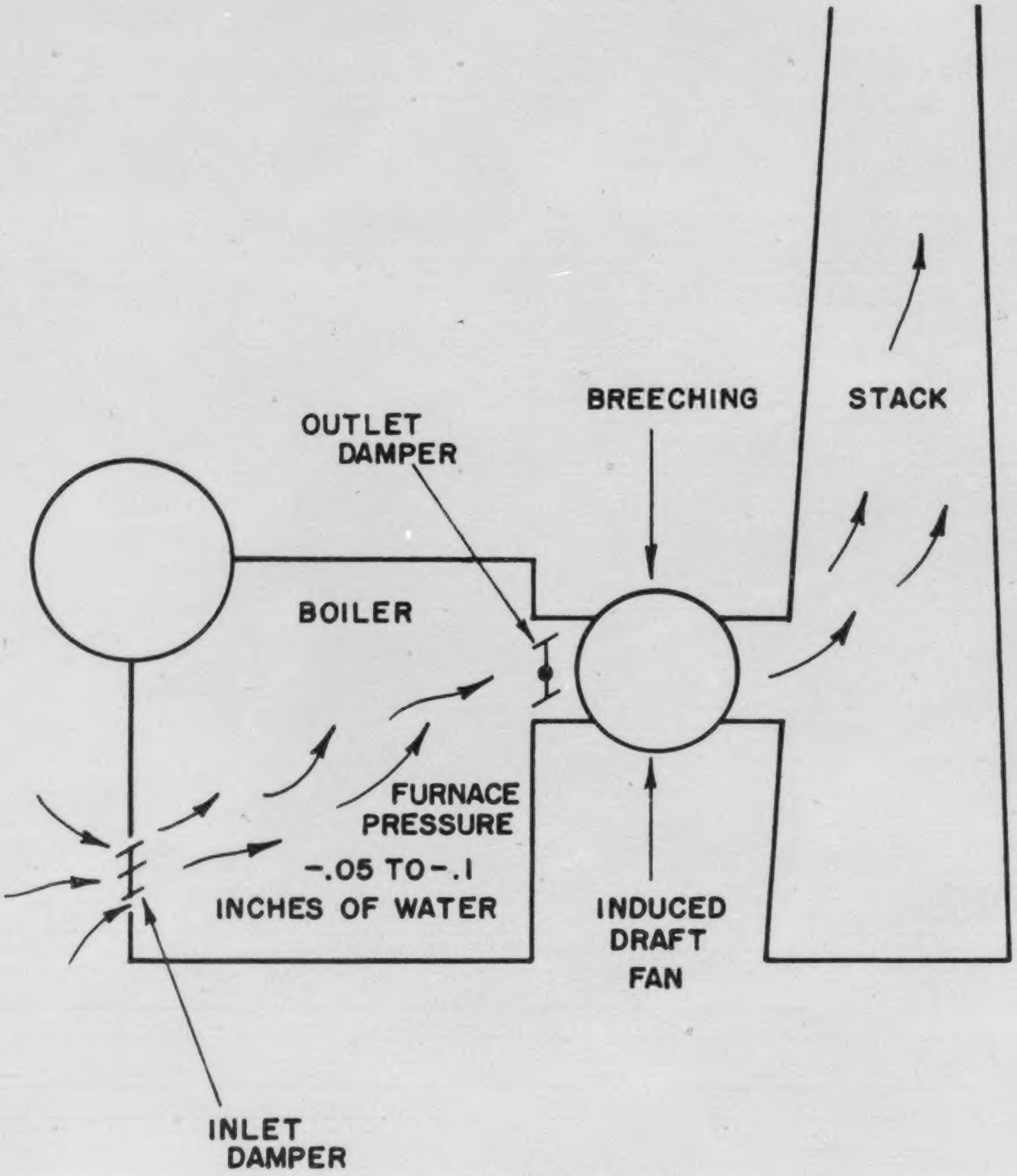
NATURAL DRAFT

5-C-1-1


BREECHING
STACK
BOILER
INLET DAMPER
FURNACE PRESSURE -.05 TO -.1 INCHES OF WATER
OUTLET DAMPER
FORCED DRAFT FAN

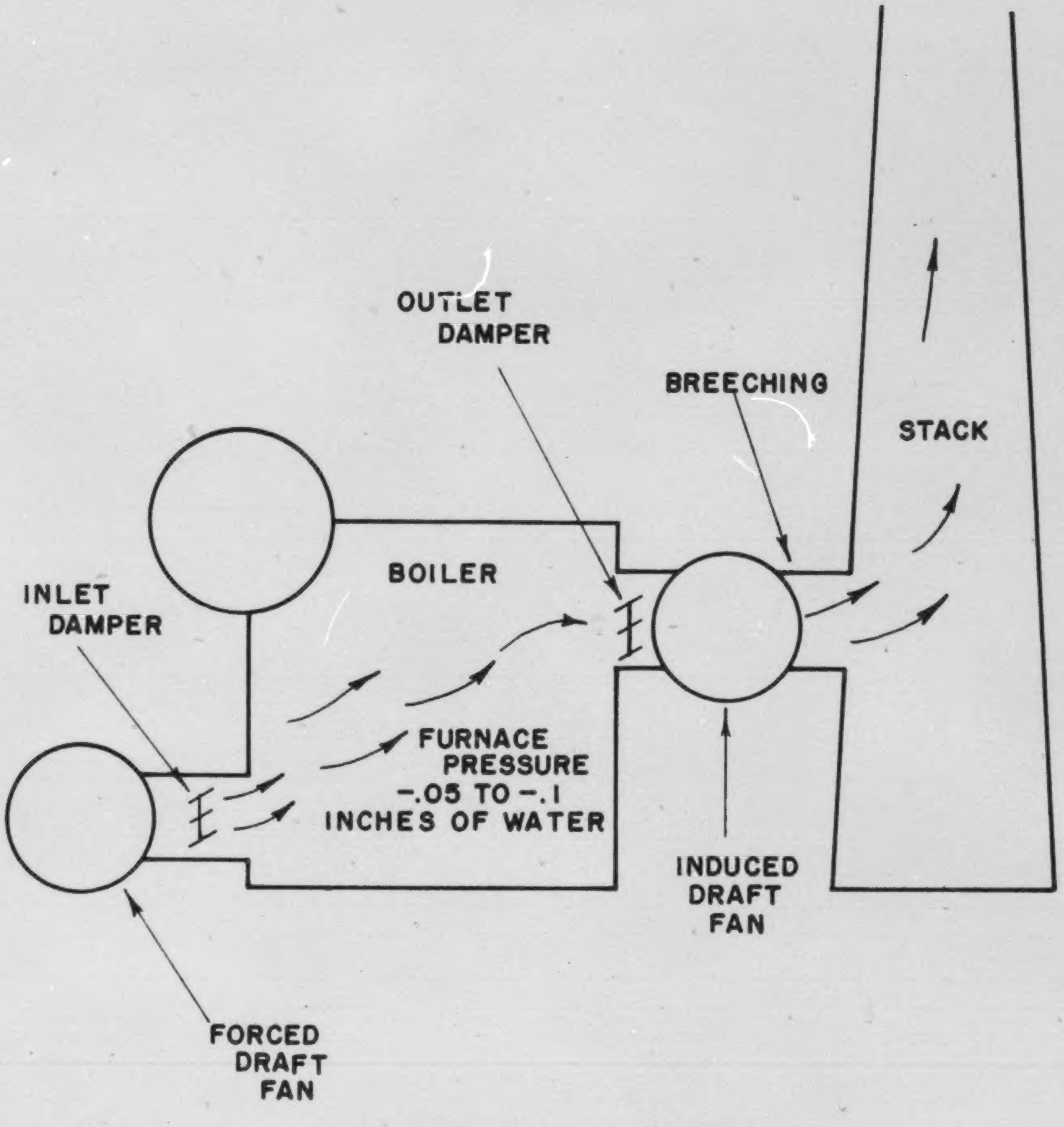
MECHANICAL DRAFT
FORCED

5-C-1-2


BREECHING
STACK
OUTLET DAMPER
BOILER
FURNACE PRESSURE
-.05 TO -.1 INCHES OF WATER
INDUCED DRAFT FAN
INLET DAMPER

MECHANICAL DRAFT
INDUCED

5-C-1-3


OUTLET DAMPER
BREECHING
STACK
BOILER
INLET DAMPER
FURNACE PRESSURE -.05 TO -.1 INCHES OF WATER
INDUCED DRAFT FAN
FORCED DRAFT FAN

MECHANICAL DRAFT
COMBINATION
FORCED AND INDUCED

5-C-1-4

Objectives:

1. Be able to write the formula that is used to determine the theoretrical amount of draft produced by a chimney.
2. Be able to calculate the theoretical amount of draft produced by a chimney using the above formula.

Information: Draft is produced by means of a chimney that contains gases at a higher temperature than the surrounding air. The weight of a column of hot gases in the chimney is less than that of a column of air at outside temperature. The amount of draft produced depends on the height of the chimney and the difference between the outside and inside gas temperature.

The following formula is used for calculating the theoretical draft produced by a chimney.

$$D = .52HP\left(\frac{1}{T_a} - \frac{1}{T_s}\right)$$

where

D = draft at the base of the chimney. Expressed in inches of water.
H = height in feet of chimney
P = atmospheric pressure (14.7 p.s.i.a.)
T_a = outside temperature in absolute degrees Rankine.
T_s = gas temperature in absolute degrees Rankine.

Note: To change °F to °R, add 460.
Example: 20°F to °R
$20^\circ + 460^\circ = 480^\circ$R.

Sample problem:
A plant has a chimney 200 feet high. The stack temperature is 450°F and the outside temperature is 100°F. Find the theoretical draft in inches of water.

$$D = .52\ HP\left(\frac{1}{T_a} - \frac{1}{T_s}\right)$$
$$D = .52 \times 200 \times 14.7\left(\frac{1}{560} - \frac{1}{910}\right)$$
$$D = 1528.8\ (.0017 - .0010)$$
$$D = 1528.8 \times .0007$$
$$D = 1.07016 \text{ inches of water.}$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. a. A plant has a chimney 185′ high. It carries a stack temperature of 485°F. The outside temperature in winter is 40°F. What is the draft in inches of water?
   b. In summer the temperature is usually 90°F. What is the draft in inches of water?
2. a. A plant has a chimney 175′ high. The stack temperature is 540°F. under full load. The outside temperature is 60°F. What is the draft in inches of water?
   b. When a plant is under light load and the stack temperature drops to 350°F., what is the draft in inches of water?
3. A plant has a chimney 110′ high. The stack temperature is 425°F and the outside temperature is usually 45°F in the winter and 85°F in the summer. What is the draft in inches of water in:
   a. winter
   b. summer
4. Change the following to degrees Rankine:
   a. 60°F
   b. 40°F
   c. 150°F
   d. 200°F
   e. 30°F
5. a. A plant has a chimney 175′ high. The stack temperature is 450°F and the outside temperature in the winter is 60°F. What is the draft in inches of water?
   b. In the summer when the outside temperature is 90°F, what is the draft in inches of water?
6. a. A plant chimney is 250′ high under full load and the stack temperature is 500°F. When the outside temperature is 45°F, find the draft in inches of water.
   b. Under a light load, the stack temperature drops to 350°F. Find the draft in inches of water.

Main and Auxiliary Feed-Water Piping — Assignment 6-A-1

Objectives:

1. Be able to trace every possible way of getting water into a boiler.
2. Be able to explain what to do in the event of low water in a boiler.

Information: We have discussed the importance of feed water in a boiler. By this time, you should be familiar with the feed-water lines in our boiler room. Upon taking a job in a strange boiler room, a fireman's first responsibility is to trace the feed-water lines in his plant and find every possible way of getting water to the boilers. In an emergency there is no time for research; he must know what to do immediately. In many plants it is only a matter of three or four minutes from the time a boiler starts to lose water until it is dry.

Starting at the open feed water heater, you should carefully trace the main feed water line. Take note of all bypasses around heaters and regulators. The line will end after the stop and check valve at the boiler drum. In some plants you will find that an auxiliary line has been installed and goes directly from the feed water pump to the feed-water stop and check valve. This line is used in emergencies only. Makeup water is usually added at the open feed-water heater through a float-controlled valve with a bypass around it.

Feed-water piping is usually constructed of steel and must conform to the specifications for temperature and pressure. The A.S.M.E. Code covers certain sections of the feed-water line; this was discussed in Unit 3-D-1. Please refer to the drawing that you did for that assignment for exact details.

References:

A.S.M.E. Code, Section I
Elementary Steam Power Engineering

Assignment:

1. How many ways are there of getting water into a steam boiler? Explain.
2. Why is it important to know every possible way of getting water to a boiler?
3. What is the purpose of a bypass on a feed-water line?
4. What part of the feed-water line is covered under the A.S.M.E. Code?
5. If you were carrying 100 p.s.i. of steam on a boiler and your feed water pumps failed, what would you do to protect your boiler from overheating because of low water?

Feed-Water Line Valves — Assignment 6-A-2

Objectives:

1. Be able to identify the types and describe the purpose of the valves found on a feed-water line.
2. Be able to explain the A.S.M.E. Code requirements for feed-water line valves.

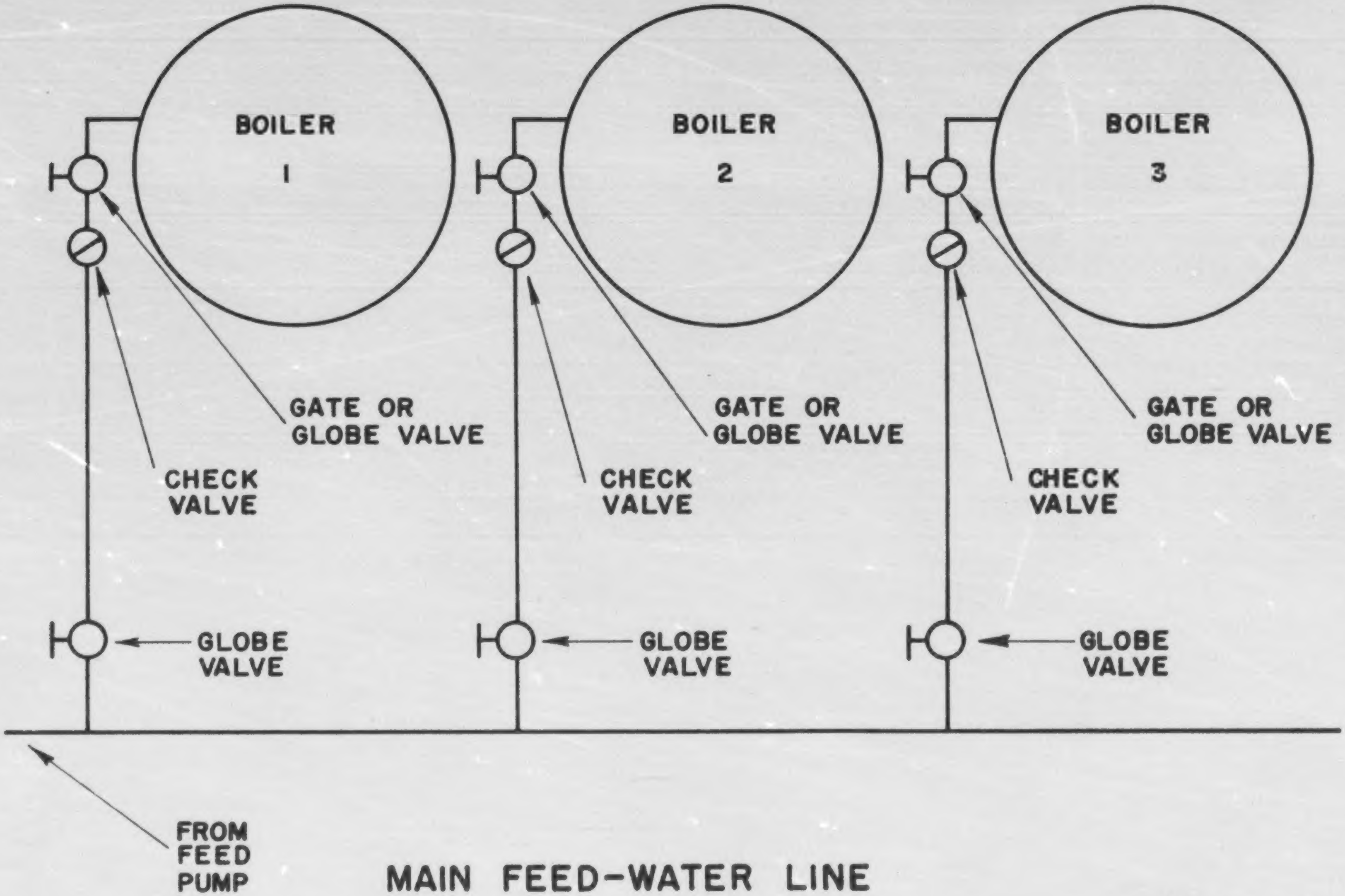
Information: The feed line on a steam boiler shall be provided with a check valve and a gate, or globe valve, located close to the boiler shell. The gate, or globe valve, shall be between the check valve and the boiler. When a globe valve is used for this purpose, it must be installed so that the pressure from the feed-water pump is under the seat of the valve.

When two or more boilers are fed from a common source, there shall be a globe valve located on each branch line between the check valve and the main line. All valves must conform to the pressures and temperatures at which they will be operated. The valve closest to the shell of the boiler is required in case the check valve should fail. Then the boiler water would flow back through the feed-water line. This valve is also used when repairing the check valve. Without it, it would be necessary to take the boiler off the line. The globe valve on the branch line can be used to regulate the flow of feed water if the feed-water regulator is not functioning.

References: *A. S. M. E. Code,* Section I
Elementary Steam Power Engineering

Assignment:

1. What types of valves are used on feed-water lines?
2. Why are these types of valves used?
3. What are the advantages of using a globe valve rather than a gate valve?
4. According to the A.S.M.E. Code, how should the valves on the feed-water lines be installed? Why?


BOILER
1
BOILER
2
BOILER
3
GATE OR GLOBE VALVE
CHECK VALVE
GATE OR GLOBE VALVE
CHECK VALVE
GATE OR GLOBE VALVE
CHECK VALVE
GLOBE VALVE
GLOBE VALVE
GLOBE VALVE
FROM FEED PUMP

MAIN FEED-WATER LINE

6-A-2-1

Open Feed-Water Heater — Assignment 6-B-1

Objectives:

1. Be able to explain the purpose of an open feed-water heater.
2. Be able to describe how an open feed-water heater functions.
3. Be able to describe how an open feed-water heater is constructed.

Information: For every 10° rise in feed-water temperature, you will get about a 1% savings in fuel. This savings alone is reason enough for having an open feed-water heater. But the heater does much more. It is open to the atmosphere and vents out oxygen and other non-condensable gases. Oxygen in the boiler leads to pitting and corrosion.

All condensate returns come back to the open feed-water heater so it acts as a reservoir for the feed-water pump to get its suction. It is equipped with a float-controlled valve, and city water can be added to the system automatically. The open heater usually has an oil baffle and cake filter bed to trap out any oil that might have been picked up by the return condensate. The heater also picks up some of the scale-forming salts contained in the city water makeup; these salts start to settle out at about 150° F. Although the open feed-water heater is vented to the atmosphere, it still will carry from 2 to 7 pounds of steam pressure. The steam is controlled by a balanced valve vented to the atmosphere. If steam pressure gets too high, it could cause the temperature of water to rise and cause the feed-water pump to become steam bound. The heater has a pressure gage, safety valve, gage glass, and thermometer which are all necessary for proper operation and safety.

Figure 6-B-1-1 shows how the heater works. Condensate enters at the top and cascades down over trays. The steam coming in from the side helps break up the condensate returns and thus drive off the oxygen and other entrained gases. The steam coming into the heater must pass through an oil baffle where any entrained oil will separate out and be discharged waste. The open feed-water heater also has an internal overflow to protect the heater and the system from flooding.

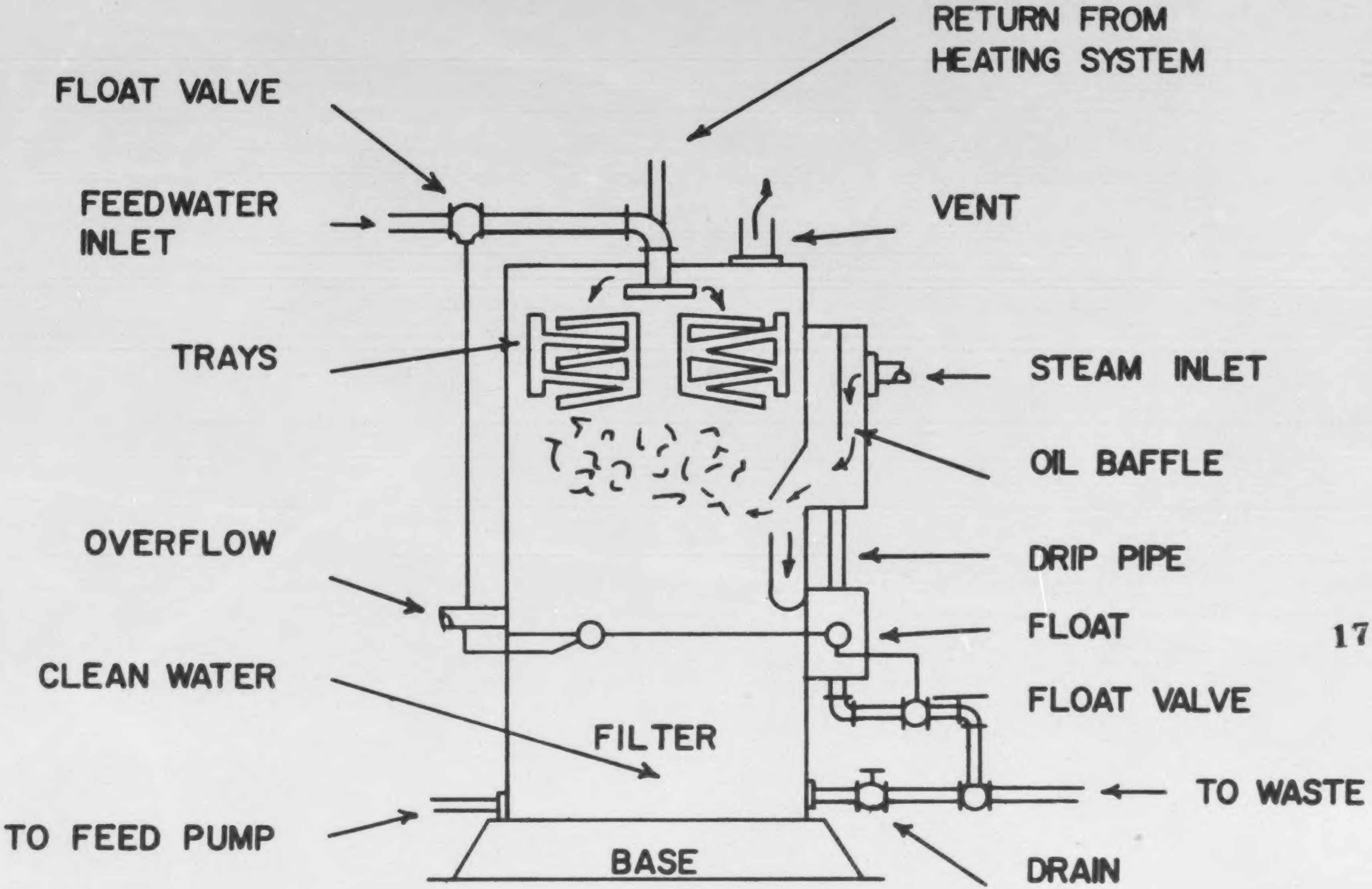
The open feed-water heater is located on the suction side above the feed-water pump. This is necessary so that the feed-water pump will be supplied with a head pressure allowing higher feed-water temperatures. Remember, for each vertical foot of water, you have a pressure of .433 pounds. Higher pressure means a higher boiling point. The open feed-water heater should be opened once a year; the trays removed and it should be thoroughly cleaned. After the heater has been wire brushed and flushed, all internal parts should be painted with a special material to inhibit corrosion.

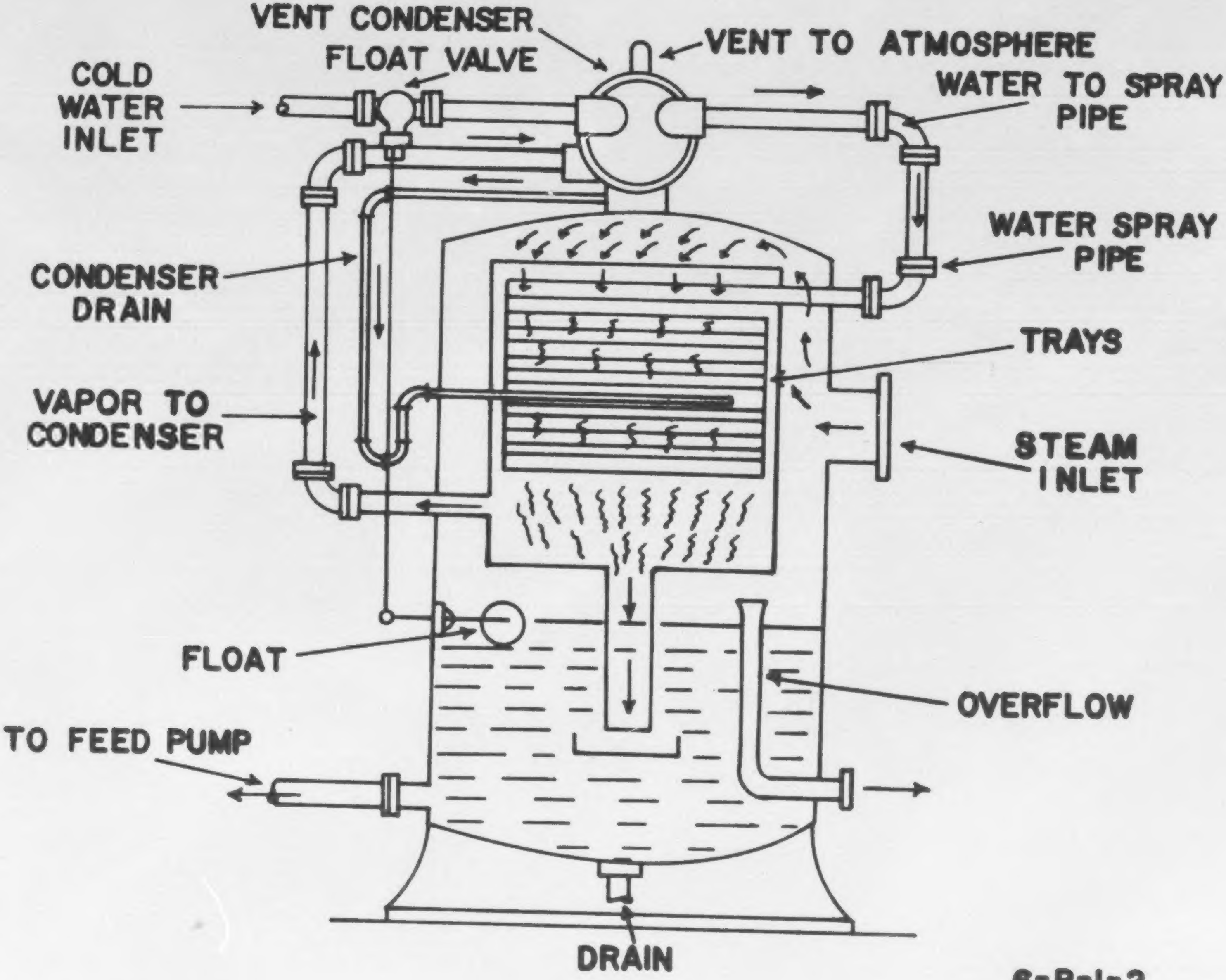
Figure 6-B-1-2 shows another feed-water heater with a vent condenser. All condensate returns and city water makeup must pass through the vent condenser before it can enter the heater proper. The vent condenser separates air from water vapor; the air is discharged to the atmosphere and the condensate is discharged to the heater. This type of heater is called a deaerating feed-water heater.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Where is the open feed-water heater located? Explain why.
2. What functions are performed by an open feed-water heater?
3. What governs the temperature you can carry in an open feed-water pump?
4. What is the purpose of an internal overflow in an open feed-water heater?
5. What does the vent condenser do in a deaerating heater?
6. What dangers are involved when using an open feed-water heater to the boiler?


RETURN FROM HEATING SYSTEM
FLOAT VALVE
FEEDWATER INLET
VENT
TRAYS
STEAM INLET
OIL BAFFLE
OVERFLOW
DRIP PIPE
FLOAT
CLEAN WATER
FLOAT VALVE
FILTER
TO WASTE
TO FEED PUMP
BASE
DRAIN


VENT CONDENSER
FLOAT VALVE
VENT TO ATMOSPHERE
COLD WATER INLET
WATER TO SPRAY PIPE
WATER SPRAY PIPE
CONDENSER DRAIN
TRAYS
VAPOR TO CONDENSER
STEAM INLET
FLOAT
OVERFLOW
TO FEED PUMP
DRAIN

6-B-1-2

Efficiency of Open Feed-Water Heaters

Assignment 6-B-1-M1

Objective: 1. Be able to calculate the percent fuel savings from heating feed water.

Information: In an open feed-water heater, the steam and water mix to raise the temperature of the water. If exhaust steam from turbines, engines, or reciprocating pumps is used for this purpose, large fuel savings and higher plant efficiency can be obtained. For approximately every 10°F rise in feed-water temperature, there is a 1% saving in fuel. The following formula can be used to calculate the percent fuel saving due to feed-water heating:

$$\text{Percent Fuel Saving} = \frac{\text{Temp. of Water Leaving} - \text{Temp. of Water Entering} \times 100}{\text{B.t.u. in Exhaust Steam} - (\text{Temp. of Water Entering} - 32)}$$

$$\text{or \% Saving} = \frac{T_L - T_E}{H_E - (T_E - 32)} \times 100$$

The heat in the exhaust steam is 1150 B.t.u. per pound. The temperature of the water entering the heater is at 55°F; it leaves at a temperature of 195°F. The savings that result from this preheating would be:

$$\text{\% Saving} = \frac{T_L - T_E}{H_E - (T_E - 32)} \times 100$$

$$\text{\% Saving} = \frac{195 - 55}{1150 - (55 - 32)} \times 100$$

$$\text{\% Saving} = \frac{140}{1127} \times 100$$

$$\text{\% Saving} = 12.42\%$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Steam leaving an engine is exhausted to a heater. This steam heats the feed water from 60°F to 155°F. The heat content of the steam is 1100 B.t.u.'s per pound. Find the saving in fuel that would result from this preheating.
2. Find the fuel saving when using exhaust steam to preheat feed water with the following conditions:

a.	120°F – 212°F	1160	B.t.u./lb	exhaust steam
b.	80°F – 206°F	1174	"	"
c.	70°F – 180°F	1077	"	"
d.	180°F – 220°F	1083	"	"
e.	100°F – 150°F	1096	"	"
f.	165°F – 218°F	1176	"	"
g.	90°F – 190°F	1156	"	"

Objectives:

1. Be able to explain the purpose of a closed feed-water heater.
2. Be able to locate the closed feed-water heater.
3. Be able to describe the basic construction of a closed feed-water heater.

Information: The closed feed-water heater is located after the feed-water pump in the feed-water system. It heats the feed water to a much higher temperature than the open heater. The final outlet temperature is determined by the steam pressure in the heater and the rate of flow of water through it. In this type of heater, the steam and water do not come in direct contact with each other. Water passes through the tubes, and steam is in the shell (around the tubes). Because this type of heater is on the discharge side of the pump, the feed-water temperature can be raised because there is no danger of the feed pump becoming vapor bound, which is possible with the open feed-water heater. When a closed feed-water heater is used, it reduces the thermal shock on the parts of the boiler where the feed water is introduced. It can also increase the overall plant efficiency if the steam is bled or extracted from a steam turbine and used in the heater.

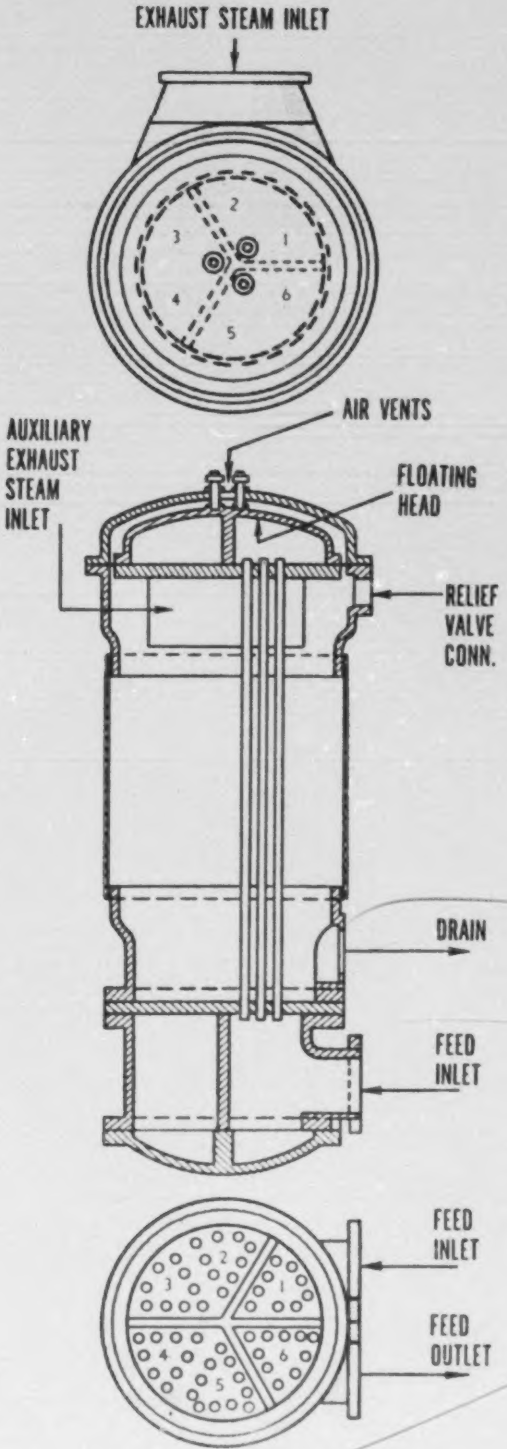
A closed feed-water heater can be either vertical or horizontal and single pass or multi-pass. It is basically a steel shell containing a large number of small tubes that are secured into two tube sheets. Expansion and contraction of the shell and tubes has to be taken into careful consideration when designing these heaters. Steam enters the upper part of the shell, and the condensate is removed at the lowest section of the shell. It must be equipped with safety and relief valves, stop valves, and a by-pass arrangement to facilitate taking the heater out of service for cleaning or repair.

References:

Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. What is a closed feed-water heater?
2. Where is it located in a feed-water system?
3. Can you increase the efficiency of a plant if you use a closed feed-water heater? Explain.
4. What is the main purpose of using a closed feed-water heater?
5. How is a closed feed-water heater constructed?


EXHAUST STEAM INLET
2
3
1
4
6
5
AIR VENTS
AUXILIARY EXHAUST STEAM INLET
FLOATING HEAD
RELIEF VALVE CONN.
DRAIN
FEED INLET
FEED INLET
FEED OUTLET
2
3
1
4
6
5

SIX-PASS CLOSED FEED-WATER HEATER

Objectives:

1. Be able to explain the purpose of the fuel economizer.
2. Be able to locate the fuel economizer.

Information:

An economizer must be located so that it can utilize the heat in the gases of combustion to heat the boiler feed water. It is sometimes referred to as a fuel saver and can increase the overall plant efficiency from 4 to 20% depending on plant operating conditions. You should remember that for every 10° rise in feed-water temperature, we realize a 1% savings in fuel.

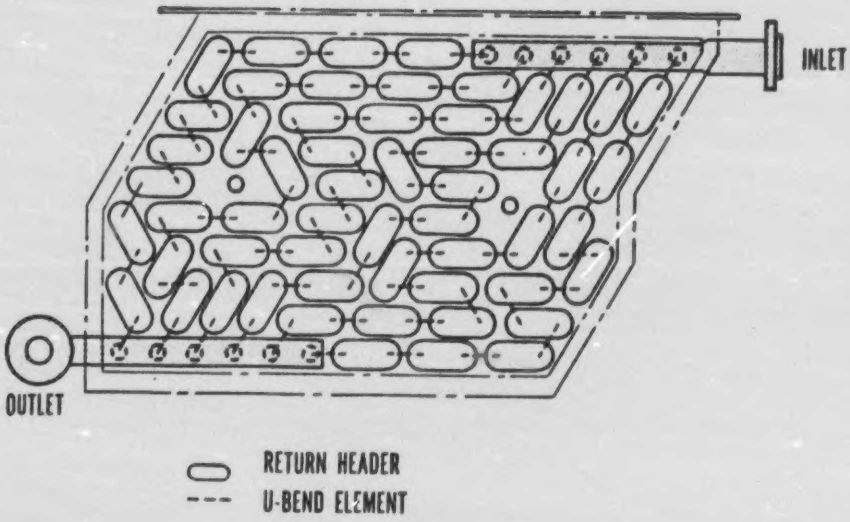
Economizers are used in plants that have a rather steady load. If the plant load was a fluctuating load, it is possible to cause the economizer tubes to sweat. Since it is located in the direct path of the gases of combustion, it will have some soot present. Soot plus water equals trouble due to sulfuric acid attack.

References:

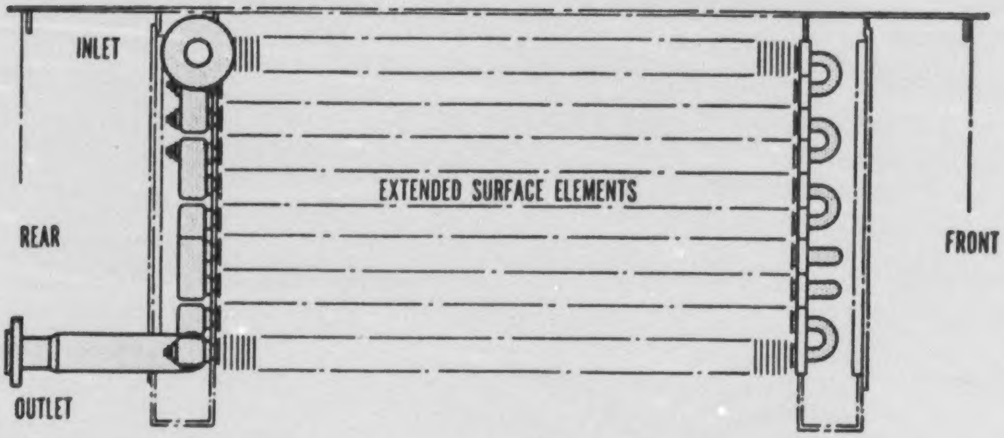
Steam Plant Operation
Elementary Steam Power Engineering
Practical Heat

Assignment:

1. What is a fuel economizer?
2. Where are they generally located?
3. What are the average temperatures of feed-water entering and leaving the economizer?
4. Why is it necessary to use an induced draft fan when economizers are used?
5. a. What is a parallel flow economizer?
   b. What is a conterflow economizer?
   c. Which is more efficient?
6. Indicate the typical heat balance in a modern plant for:
   a. Boiler efficiency.
   b. Boiler efficiency with economizer.
   c. Boiler efficiency with economizer and air preheater.
7. Briefly describe the unit type and the integral type of economizer.
8. Why is it possible to use steel tube economizers?
9. What types of bypasses are needed on economizers, and why are they necessary?

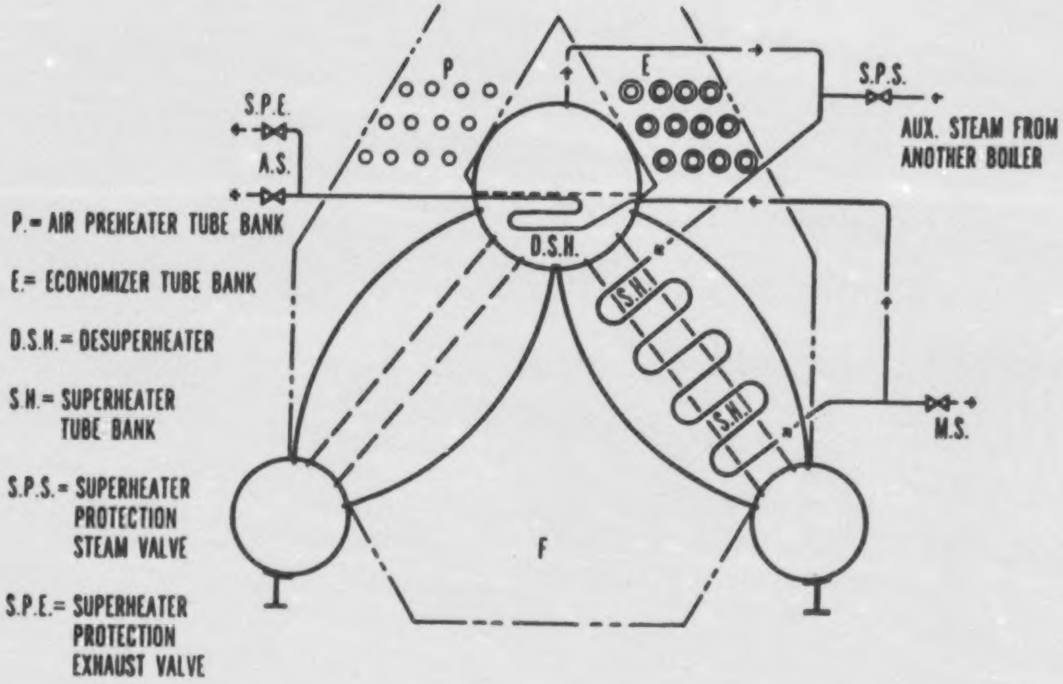

INLET
OUTLET
RETURN HEADER
U-BEND ELEMENT

REAR END VIEW


INLET
EXTENDED SURFACE ELEMENTS
REAR
FRONT
OUTLET

SIDE ELEVATION

6-B-3-1


P
E
S.P.E.
A.S.
S.P.S.
AUX. STEAM FROM
ANOTHER BOILER
D.S.H.
S.H.
S.H.
M.S.
F
P.= AIR PREHEATER TUBE BANK
E.= ECONOMIZER TUBE BANK
D.S.H.= DESUPERHEATER
S.H.= SUPERHEATER
TUBE BANK
S.P.S.= SUPERHEATER
PROTECTION
STEAM VALVE
S.P.E.= SUPERHEATER
PROTECTION
EXHAUST VALVE

Schematic showing location of economizer -- air preheater – superheater and de-superheater

6-B-3-2

Controls: Feed-Water Regulator — Assignment 6-C-1

Objectives:

1. Be able to describe the purpose and to locate the feed-water regulators.
2. Be able to identify the types of feed-water regulators.
3. Be able to operate a feed-water regulator.

Information: To increase the overall efficiency of a boiler room, it is necessary to control the amounts of water being fed to a boiler. By maintaining a steady minimum water level, we can reduce fuel consumption, cut down on boiler thermal shock, reduce danger of carryover, and reduce danger of low water that could lead to overheated, burned out tubes or even a boiler explosion.

All feed-water regulators, regardless of their make or design, must be located at the normal operating water level.

A feed-water regulator must be blown down once a shift in order to make sure it will operate. This is a broad statement to make since there are some exceptions to this rule. It is the operator's responsibility to know his own feed-water regulator and what is recommended for proper operation.

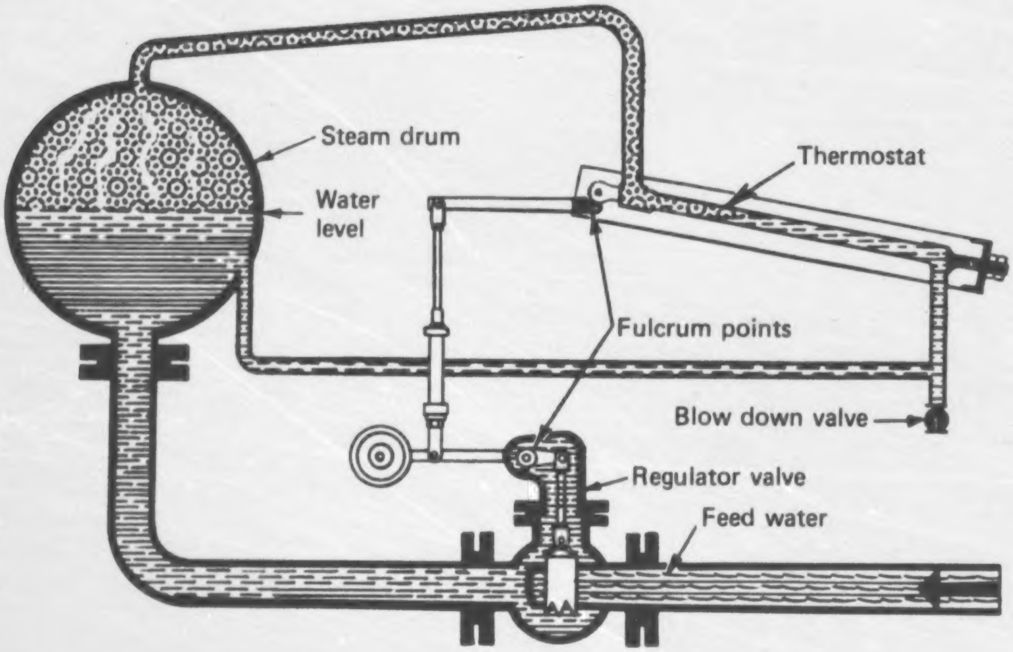
Any control is only as good as the man who is watching and maintaining it.

References:

Steam Plant Operation
Elementary Steam Power Engineering
Boiler Room Questions and Answers
Manufacturers Data Sheets

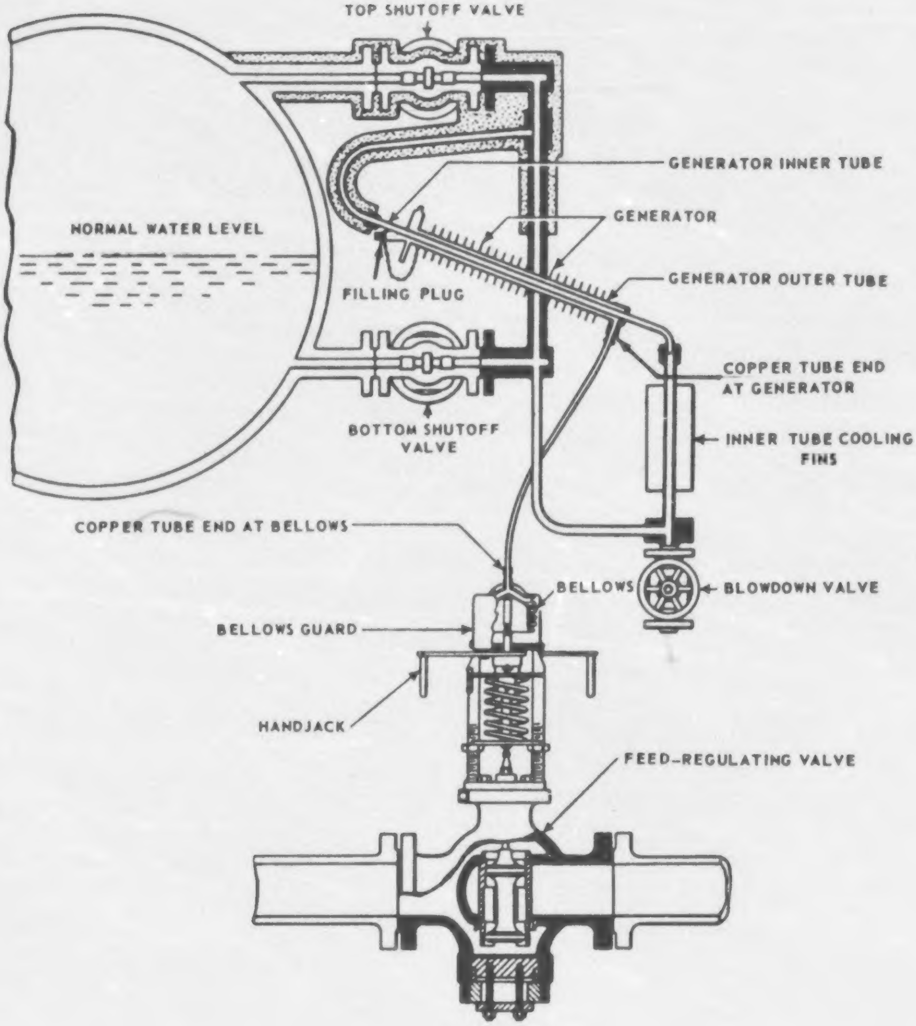
Assignment:

1. What is the purpose of a feed-water regulator?
2. Where are feed-water regulators located on a boiler?
3. What type of feed-water regulators do we have in our plant?
4. Describe in detail how our feed-water regulators operate.
5. What could happen if our feed-water regulator were not blown down regularly?
6. Describe in detail the Copes thermostatic expansion type feed-water regulator. Include location, how it is connected, and how it operates.
7. If you blew down our feed-water regulator and the boiler did not shut down, what would you do?
8. What would you do if you were firing a boiler with a Copes regulator and it stuck in an open position?


Steam drum
Thermostat
Water level
Fulcrum points
Blow down valve
Regulator valve
Feed water

THERMO-EXPANSION FEED-WATER REGULATOR

6-C-1-1


TOP SHUTOFF VALVE
GENERATOR INNER TUBE
GENERATOR
NORMAL WATER LEVEL
GENERATOR OUTER TUBE
FILLING PLUG
COPPER TUBE END AT GENERATOR
BOTTOM SHUTOFF VALVE
INNER TUBE COOLING FINS
COPPER TUBE END AT BELLOWS
BELLOWS
BLOWDOWN VALVE
BELLOWS GUARD
HANDJACK
FEED-REGULATING VALVE

THERMO-HYDRAULIC FEED-WATER REGULATOR

6-C-1-2

Objectives:

1. Be able to describe the purpose and to locate automatic city water makeup valves.
2. Be able to describe the fireman's responsibility regarding automatic city water makeup valves.

Information: It take one pound of water to make one pound of steam. If your system is tight and you get back all of your returns, you will need little or no city water makeup. But, as in most high pressure plants, some of your returns are lost due to leaks, and some are contaminated and dumped. It is often necessary to add 50% makeup water.

The purpose of an automatic city water makeup valve is to automatically add city water to the boiler or system to keep it operating. It is mechanical in operation; a float opens or closes a valve in the city water line. In a low-pressure plant, they are located a little below the normal operating water level. The top line connects to the highest part of the steam side of the boiler. The bottom is well below the normal operating water level (usually 6" below the center line of the boiler). The city water is discharged directly into the boiler because city water pressure is greater than the boiler pressure. It should be noted that an automatic city water makeup valve in a low-pressure boiler is not meant to act as a feed-water regulator. Heating plants are usually designed for 100% returns. If city water is being fed into the boiler continually, it means there is a leak in your system. You are losing good condensate and filling your boiler with city water which contains scale-forming salts. You must find and repair the leak at once.

In high pressure plants, the automatic city water makeup will be located on an open feed-water heater or a condensate return tank. This is necessary because boiler pressure is greater than city water pressure.

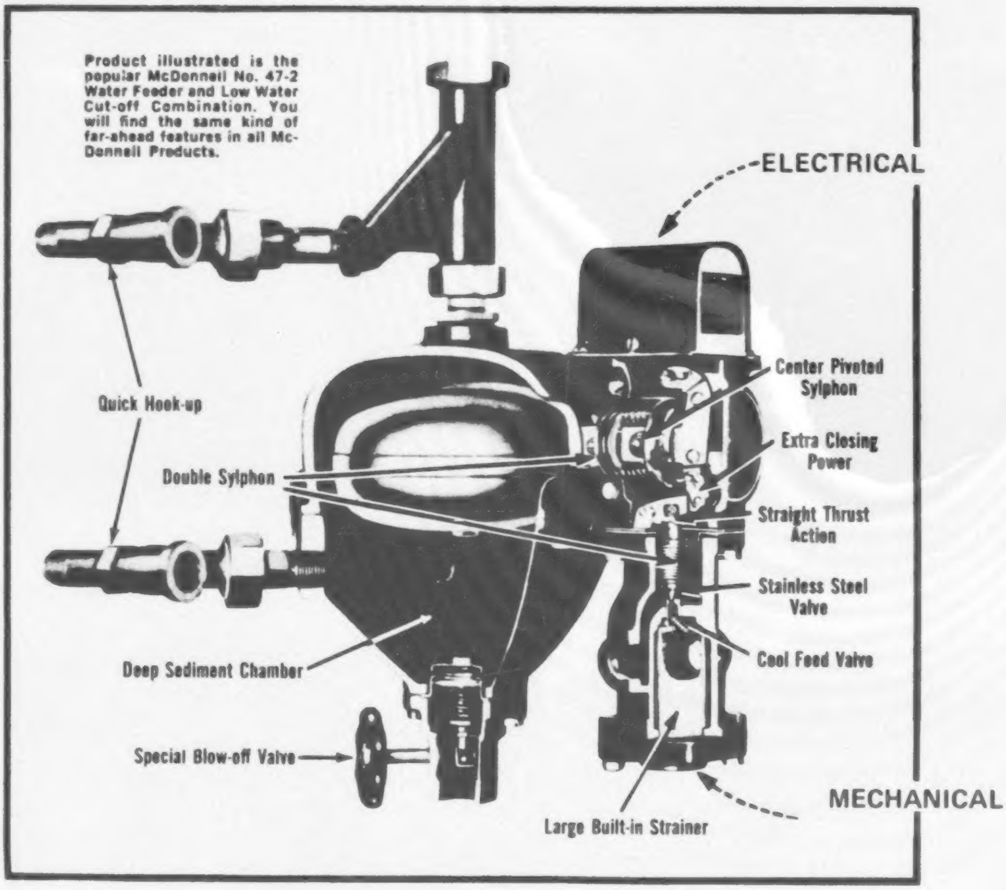
Since much of the returns are lost, it is necessary to carefully watch your feed-water treatment to prevent scale build-up.

References:

Steam Plant Operation
Elementary Steam Power Engineering
Boiler Room Questions and Answers
Low Pressure Boilers

Assignment:

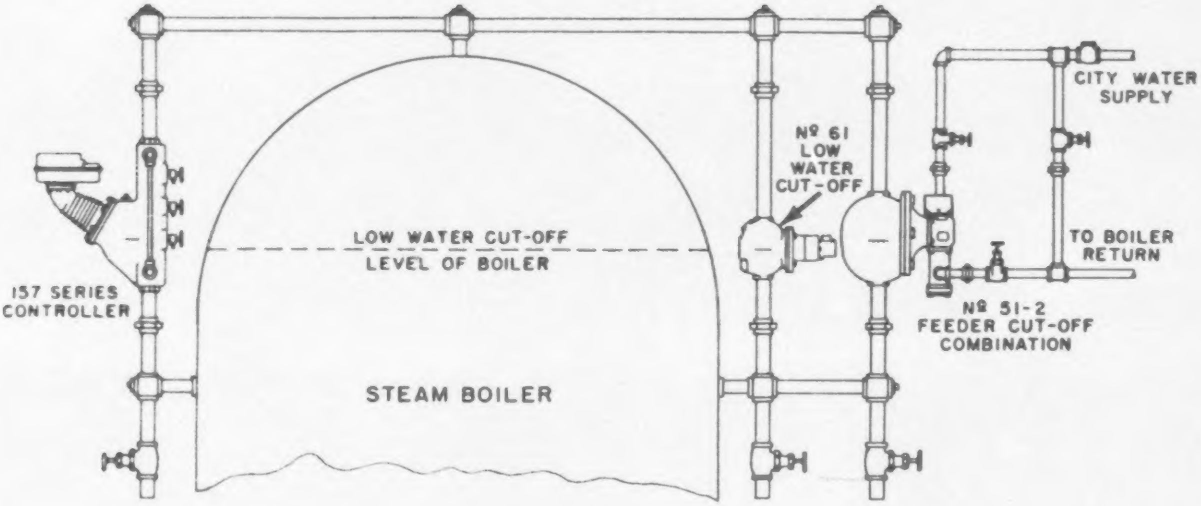
1. What is the purpose of an automatic city water makeup valve?
2. Where are they located in:
   a. low-pressure plants
   b. high-pressure plants.
3. Describe in detail how an automatic city water makeup valve works in a low-pressure plant.
4. What would happen if the automatic city water makeup valve stuck open?
5. What would happen if the automatic city water makeup valve failed to open?
6. Why is feed-water treatment more critical in a high-pressure plant than in a low-pressure plant?


Product illustrated is the popular McDonnell No. 47-2 Water Feeder and Low Water Cut-off Combination. You will find the same kind of far-ahead features in all McDonnell Products.

ELECTRICAL
Quick Hook-up
Center Pivoted Sylphon
Extra Closing Power
Double Sylphon
Straight Thrust Action
Stainless Steel Valve
Cool Feed Valve
Deep Sediment Chamber
Special Blow-off Valve
MECHANICAL
Large Built-in Strainer

AUTOMATIC CITY WATER MAKE-UP

6-C-2-1


CITY WATER SUPPLY
Nº 61 LOW WATER CUT-OFF
LOW WATER CUT-OFF LEVEL OF BOILER
TO BOILER RETURN
157 SERIES CONTROLLER
Nº 51-2 FEEDER CUT-OFF COMBINATION
STEAM BOILER

6-C-2-2

Controls: Low Water Cutoff — Assignment 6-C-3

Objectives:

1. Be able to describe the purpose and to locate a low water cutoff.
2. Be able to describe the fireman's responsibility regarding low water cutoffs.

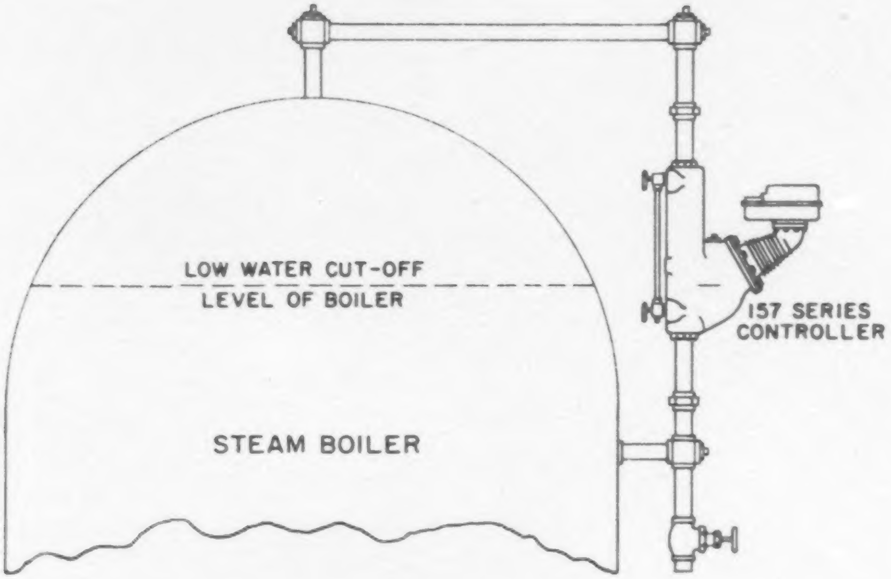
Information: The low water cutoff is an automatic device that will shut the burner off when the water is low. This protects the boiler from burning up or blowing up. The cutoff is located a little below the normal operating water level; the top line goes to the highest part of the steam side of the boiler, and the bottom connects 6" below the center line of the boiler. There should still be water showing in the gage glass when the low water cutoff comes into operation. It must be tested at least once a shift by blowing down, and it should be tested once a month by actually letting the water level in the boiler drop. This is sometimes called an evaporation test. It should be pointed out that just because a boiler is equipped with a low water cutoff it does not relieve the fireman of the responsibility of keeping careful watch of his water level. These controls can malfunction. They do not take the place of a fireman; they just assist him in running a better shift.

References:

Boiler Room Questions and Answers
Low Pressure Boilers

Assignment:

1. Discuss the purpose and location of a low water cutoff?
2. If you blew down the low water cutoff and the burner did not shut off, what procedure would you follow?
3. Why do you think it would be good engineering practice to test the low water cutoff by allowing the water level in the boiler to drop?
4. How often should a low water cutoff be tested by blowing down?
5. Must all boilers be equipped with a low water cutoff?


LOW WATER CUT-OFF
LEVEL OF BOILER
157 SERIES
CONTROLLER
STEAM BOILER

LOW WATER CUT-OFF

6-C-3

Condensate Tank: Atmospheric — Assignment 6-D-1

Objectives:

1. Be able to describe the purpose and to locate the condensate tank.
2. Be able to describe the fireman's responsibility regarding condensate tanks.

Information: The condensate return tank, by its name alone, should tell you its purpose. After the steam has left the boiler and completed its work, it condenses back into water. This water is pure, and it should be returned to the boiler to be reused. When more condensate can be reclaimed, less raw water has to be used which reduces the amount of chemicals needed by the boiler to control scale. It is often impossible to return the condensate directly to the feed-water heater which makes a condensate return tank necessary.

The condensate tank is usually located as close to the boiler room as possible. It is fitted with a gage glass and usually a city water makeup line. The tank will have a suction line going to a condensate pump. This pump will discharge the water through a pipe line to the feed-water heater. In a large plant, there may be one or more return tanks feeding one main return tank located in the boiler room. Failure of any one of these tanks to return its share of water will cause an increase in makeup water. By watching his return temperature, the fireman can tell when a failure occurs by a drop in temperature.

If the temperature of the condensate goes too high, it could cause the condensate pump to become steam bound. This increase in condensate temperature could be caused by steam traps blowing through.

References:

Low Pressure Boilers
McDonnell Miller Catalog

Assignment:

1. Discuss the purpose and general location of the condensate return tank.
2. How would the fireman know if the proper returns were not returning to the condensate tank?
3. Why do you think it is necessary to save this condensate?
4. Why is the condensate return tank fitted with an automatic city water makeup?
5. What would an increase in condensate temperature indicate?
6. Where does the condensate pump discharge?
7. If you saw traces of oil in the return tank, what procedure would you follow and how would this effect overall plant operation?

Condensate Tank: Vacuum — Assignment 6-D-2

Objectives:

1. Be able to describe the purpose and to locate the vacuum condensate tank.
2. Be able to describe how a vacuum pump works.
3. Be able to describe the fireman's responsibility regarding vacuum pumps and tanks.

Information: The vacuum condensate tank basically serves the same purpose as an atmospheric condensate tank; it reclaims condensate. It is equipped with a vacuum pump that creates a vacuum on the return line. This vacuum helps to draw condensate from the return line back to the condensate or vacuum tank. Any air or non-condensable gases are discharged to the atmosphere; and the condensate is discharged either to a feed-water heater or to a receiver of some sort. In heating plants of the low-pressure type, the condensate could be discharged directly to the boiler.

References:

Steam Plant Operation
Low Pressure Boilers
Hash Pumps Manual

Assignment:

1. What is the purpose of a vacuum pump?
2. Where do the air and non-condensable gases come from? What happens to them when they get back to the vacuum tank?
3. What is the purpose of a thermometer on the return line entering the vacuum tank?
4. What would a sudden increase in temperature indicate?
5. What could this increase in temperature cause? How would you correct it?
6. Discuss the three settings on a vacuum pump in a low-pressure heating system and when to use each.
7. What would water coming out of the atmospheric discharge line of the vacuum pump indicate?
8. Why do some plants have one vacuum tank and two vacuum pumps?

Reciprocating Pumps

Assignment 6-E-1

Objectives:

1. Be able to describe how a reciprocating pump works.
2. Be able to explain the meaning of the name plate date.
3. Be able to explain the reason why a reciprocating pump will fail to deliver water to a boiler.

Information: A reciprocating pump is a positive displacement pump. When the piston moves through each stroke, a definite amount of water is discharged. The amount delivered depends upon the size of the pump. The discharge line must be open whenever the pump is operating to prevent a pressure increase over design pressure. A safety relief valve is installed between the discharge outlet of the pump and the discharge stop valve to limit the pressure on the discharge line.

A reciprocating feed-water pump has a steam piston and a water piston. The steam piston must be 2 to 2½ times larger in area than the water piston. With this design it is possible to deliver a sufficient supply of water to a steam boiler while using the steam from the boiler to operate the pump. The location of the feed-water pump is below the open feed-water heater, or any other source of supply. This gives the pump a positive suction pressure.

A reciprocating feed-water pump will fail to supply sufficient water to a boiler for the following reasons:

1. Closed suction or discharge stop valves (Possible damage to pump unless a safety relief valve is installed.)
2. No water in open feed-water heater. (Automatic city water makeup closed or not functioning.)
3. Suction or discharge pump valves open or leaking. (Recondition valves.)
4. Water plunger rings worn allowing leakage. (Replace plunger rings.)
5. Steam piston rings or cylinders worn or broken. (Replace rings or cylinders.)
6. Steam valves worn or improperly set. (Repair or reset valves.)
7. Water cylinder vapor bound. (Reduce temperature of water to prevent flashing in the pump water cylinder.)

All reciprocating pumps have a name plate with certain numbers on it. This name plate is most important to the operating engineer. The data will tell him the size of his pump and enable him to figure out how much steam pressure is needed to obtain a certain discharge pressure. Or, he can figure the discharge pressure to be expected by knowing the amount of steam pressure on hand to drive the pump. It is also possible to calculate the gallons per minute that the pump can discharge.

The name plate data might read 4 X 2 X 6. The numbers are in inches and indicate the following:

First number – diameter of the steam piston.
Second number – diameter of water piston.
Third number – length of the stroke

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

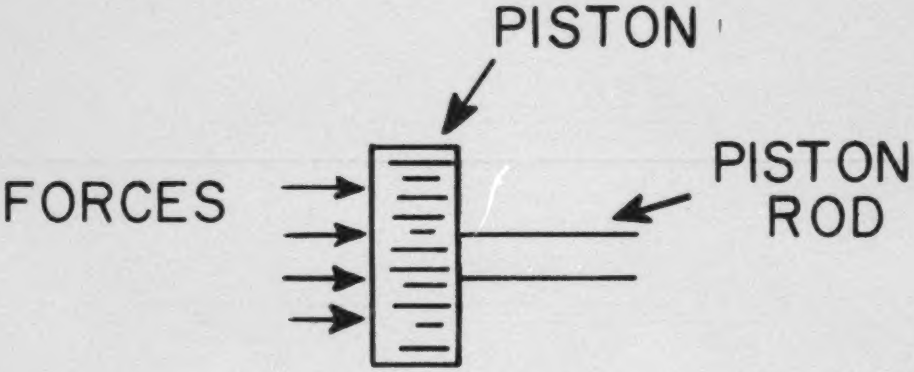
1. Explain the theory of operation of a reciprocating pump.
2. Why is it necessary to have the discharge pressure of a pump higher than the boiler pressure?
3. What does the pump name plate data, 8 X 4 X 6, mean?
4. Two reciprocating pumps have the following name plate data:
   a. 3 X 2 X 6
   b. 3 X 8 X 12
   Which would you select as a feed-water pump? Explain why?
5. Give all the reasons why a reciprocating feed-water pump would fail to supply water to a boiler.

Objectives:

1. Be able to explain what is meant by *total force = total force.*
2. Be able to find the steam pressure needed by knowing the water pressure developed when using *total force = total force.*
3. Be able to find the water pressure developed by knowing the steam pressure on hand when using *total force = total force.*

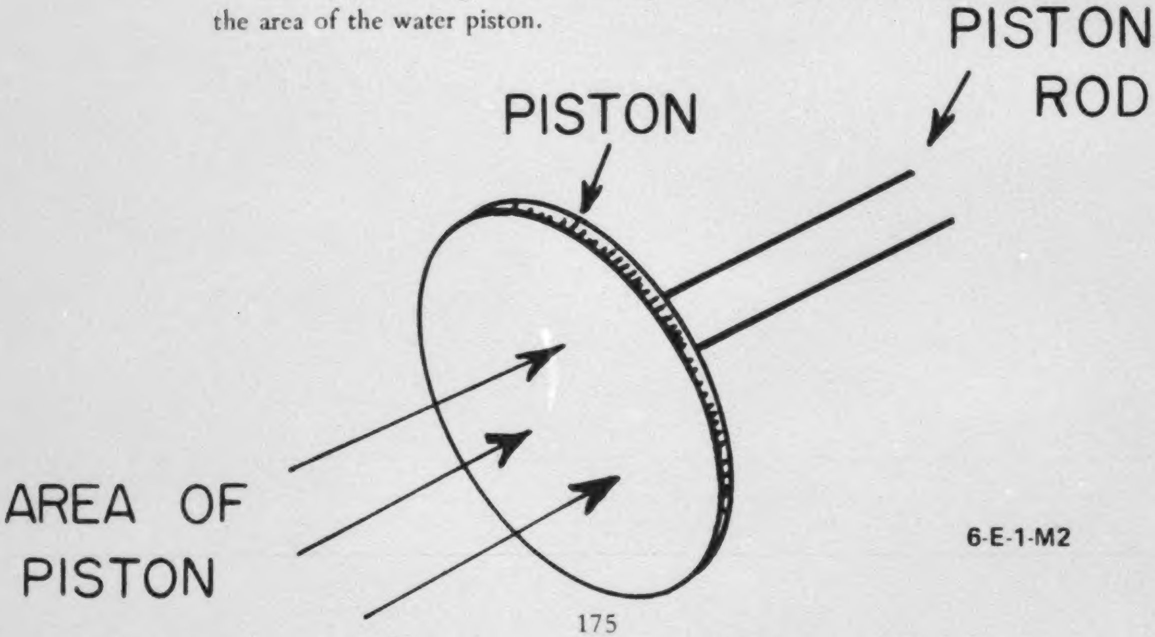
Information: What is *total force?* This term will come up all through your studies in engineering. It is a basic concept you must understand.

Total force may be defined as a sum of the forces acting in one direction. An example would be steam pressure being applied to the surface area of the head of a piston.



6-E-1-M1

The *total force* acting on the steam piston would then be the steam pressure × the area of the steam piston (the area being in square inches). The *total force* acting on the water piston would be the water pressure × the area of the water piston.



6-E-1-M2

$$\frac{D^2 \text{ S.S.} \times \text{Steam Pressure}}{D^2 \text{ W.S.}} = \text{Water Pressure}$$

$$\frac{6 \times 6 \times 150}{3 \times 3} = \text{Water Pressure}$$

$$600 \text{ p.s.i.} = \text{Water Pressure developed}$$

Procedure: After having studied the listed example given, do the following assignment.

Assignment:

1. A reciprocating pump 4 X 2½ X 6 uses steam at 200 p.s.i. Find the pressure developed on the water side and prove your answer.
2. A reciprocating pump 5 X 3 X 8 must develop 500 p.s.i. on the discharge side. Find the steam pressure needed to run this pump and prove your answer.
3. A sales representative recommends a reciprocating pump 6 X 4 X 6 to use 250 p.s.i. steam. He also states that the pump will develop 800 p.s.i. on the discharge side. It is your responsibility to OK this purchase. Prove that he is right or wrong.

Objective: Be able to calculate the pumping capacity of a reciprocating pump.

Information: The capacity in gallons per minute of any reciprocating pump can be found by using the following formula:

$$\text{G.P.M.} = \frac{\text{LANE}}{231}$$

where:

G.P.M. = Gallons per minute
L = Length of the stroke of the piston as found on the data plate
A = Area of the piston in square inches
N = Number of strokes per minute
E = Efficiency of the pump

If we multiply the length of the stroke times the area of piston, it will give us the number of cubic inches of displacement in the cylinder.

$$\text{Cubic Inches} = L \times A$$

The number of times the cylinder is cleared per minute times the cubic inches would give us the total cubic inches displaced per minute.

$$\text{Cubic Inches Per Minute} = L \times A \times N$$

We know that our pump is not 100% efficient; therefore it will discharge only a percentage (E) of its theoretical capacity.

$$\text{Actual Cubic Inches Per Minute} = L \times A \times N \times E$$

There are 231 cubic inches in a gallon. Using this fact, we can convert our cubic inches per minute into gallons per minute.

$$\text{G.P.M.} = \frac{L \times A \times N \times E}{231}$$

Example 1: A double-acting, simplex reciprocating pump is 7/8 full on each stroke, and it has a piston diameter of 4 inches with a stroke of 8 inches. Find the gallons per minute discharged when the pump runs at 120 strokes per minute.

$$\text{G.P.M.} = \frac{L \times A \times N \times E}{231}$$

L = 8"
A = .7854 × 4 × 4 (A = .7854 D^2)
N = 120
E = 7/8 = .875

$$\text{G.P.M.} = \frac{8 \times .7854 \times 4 \times 4 \times 120 \times .875}{231} = 45.696$$

Example 2: Find the gallons per minute discharged from a pump making 50 strokes per minute. The name plate data shows 8 × 10 × 12, and the pump has an efficiency of 80%.

$$\text{G.P.M.} = \frac{L \times A \times N \times E}{231}$$

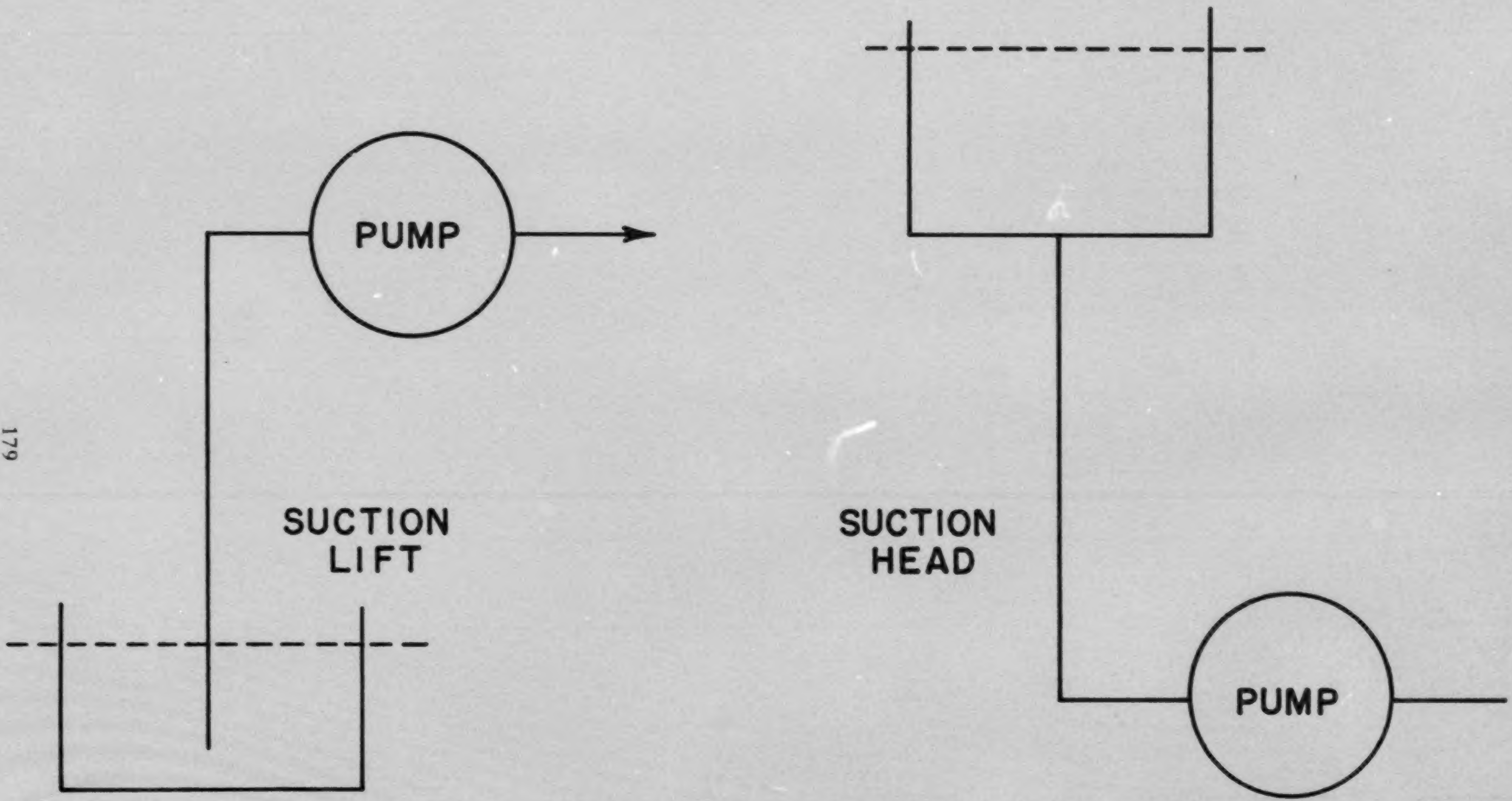
L = 12"
A = .7854 × 10 × 10
N = 50
E = .80

$$\text{G.P.M.} = \frac{12 \times .7854 \times 10 \times 10 \times 50 \times 80}{231} = 163.1$$

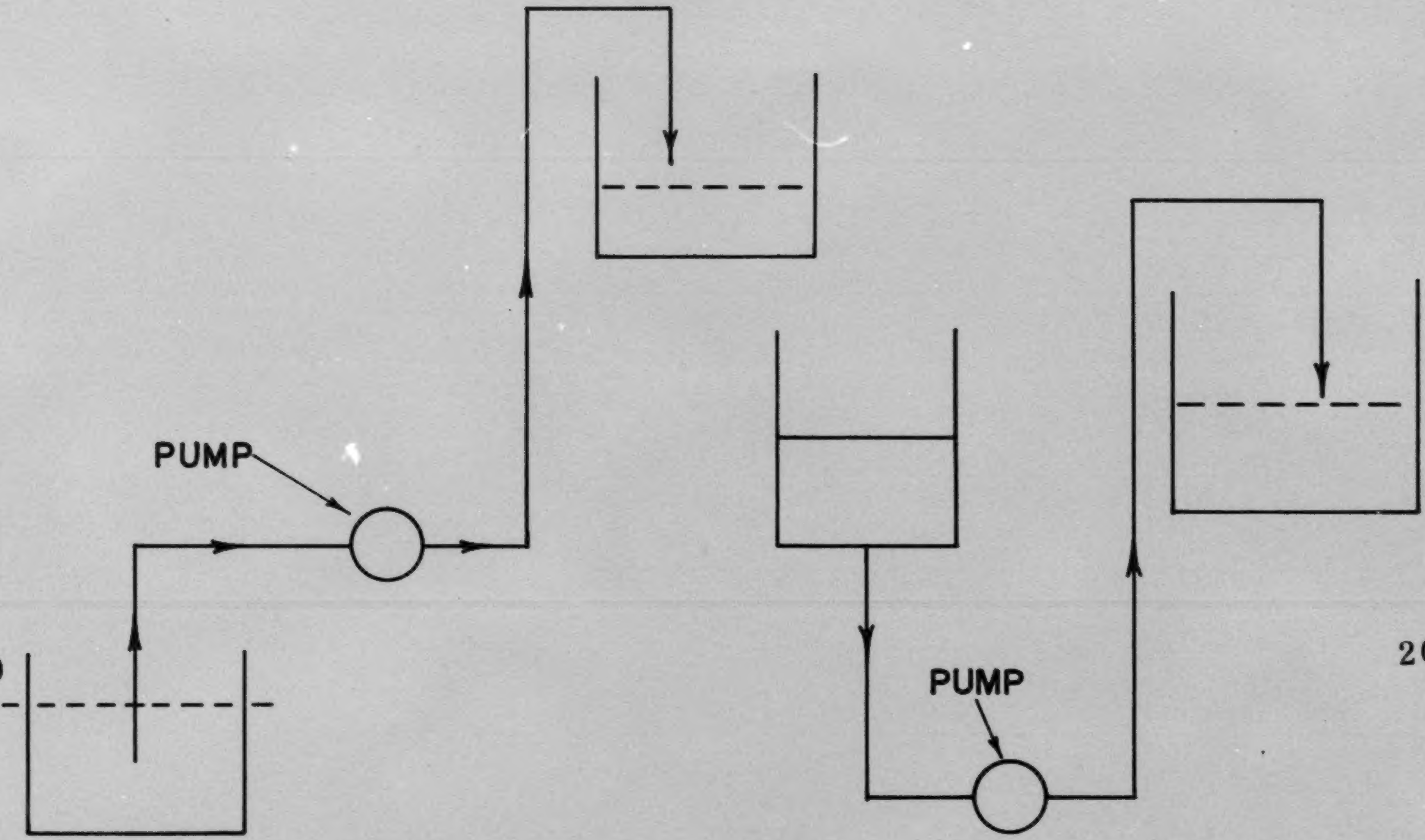
References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

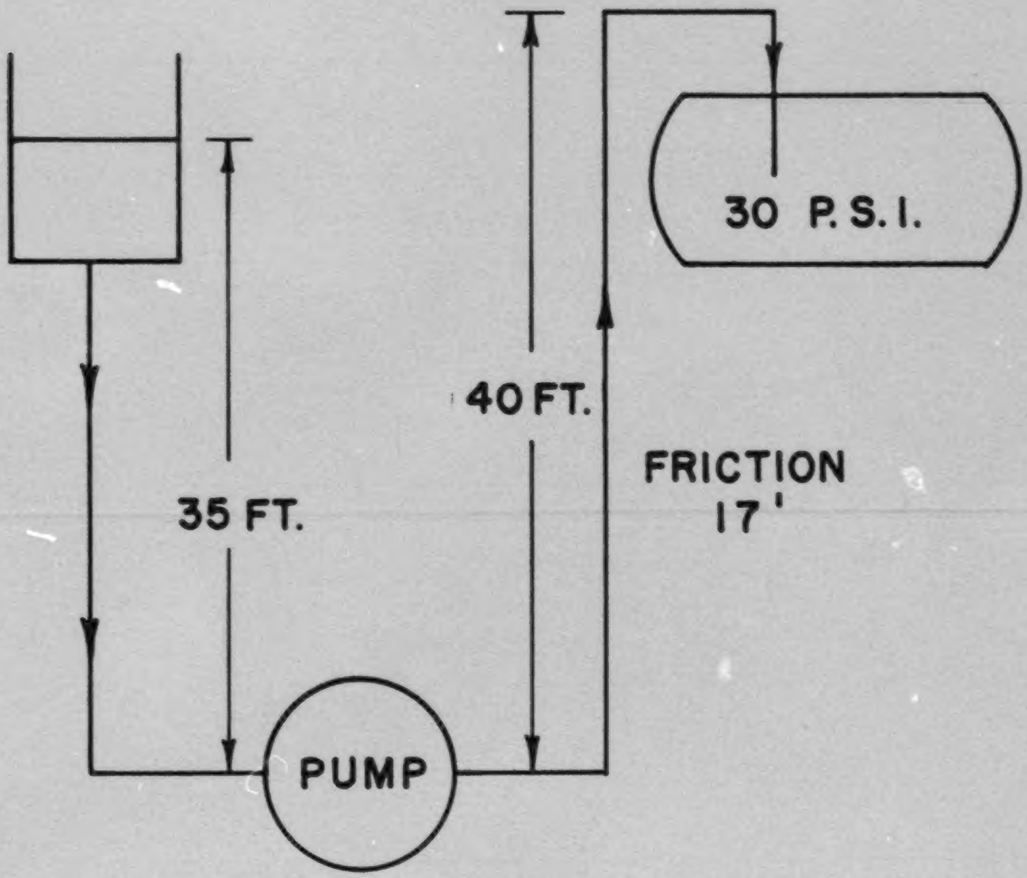
1. A simplex pump has a piston diameter of 12 inches, a stroke of 14 inches, and operates at 100 strokes per minute. What is the discharge in gallons per minute if the pump is 80% efficient?
2. A duplex pump, 12 × 16 × 18, makes 80 strokes per minute. With 75% efficiency, how many gallons can this pump discharge in a minute? In an hour?
3. A duplex pump, 3 × 2 × 3, with 75 strokes per minute, has an efficiency of 75%. Find the gallons per minute and the gallons per hour.
4. A simplex pump has a cylinder diameter of 6 inches and a stroke of 10 inches. It makes 32 strokes a minute, and the cylinder is 5/8 full each stroke. How many gallons a minute will this pump discharge?
5. How many gallons per hour will be pumped by a duplex pump having a 14" diameter steam cylinder with a stroke of 16", and an operating speed of 55 strokes per minute. It has an efficiency of 80%.


PUMP
SUCTION
LIFT
SUCTION
HEAD
PUMP

6-E-2-MI-1



6-E-2-MI-2


30 P.S.I.
40 FT.
FRICTION
17'
35 FT.
PUMP

6-E-2-MI-3

Objectives:

1. Be able to describe how a centrifugal pump works.
2. Be able to list the advantages and disadvantages of centrifugal pumps for boiler feed-water service.
3. Be able to select a centrifugal pump for boiler feed-water service.

Information: To understand how a centrifugal pump functions, let's review some of the information from last year. The impeller is the rotating element in a centrifugal pump through which liquid passes and acquires energy. The casing or housing surrounding the impeller causes the liquid to flow from the pump in a controlled manner. As the liquid passes into the rotating impeller, the kinetic energy overcomes the potential energy and gives it centrifugal force. Once the liquid is thrown from the impeller, the casing guides the liquid to its destination. The result is a workable pump for imparting energy to a liquid at one point which causes it to move to another point.

A centrifugal pump for boiler feed-water service has to meet certain conditions for pressure and volume. It is recommended that a boiler feed-water pump should have the capacity to deliver two times the maximum steaming capacity of the boiler it is supplying at the maximum allowable working pressure of the boiler.

According to the N.J. Pressure Vessel Code, if a solid fuel is being used on the boiler, it is then necessary to have two ways of supplying feed-water to the boiler, one of which must be with a steam drive.

There are a number of advantages and disadvantages in using centrifugal pumps for feed-water service. They may be listed as follows:

Advantages

1. Can be used effectively with in-line feed-water regulators.
2. Variable drive – electric motor or steam turbine.
3. Reliable
4. Fewer moving parts
5. Adaptable for on-off operation
6. Fairly constant efficiency over long running periods.
7. Capable of handling high pressure and large capacities.

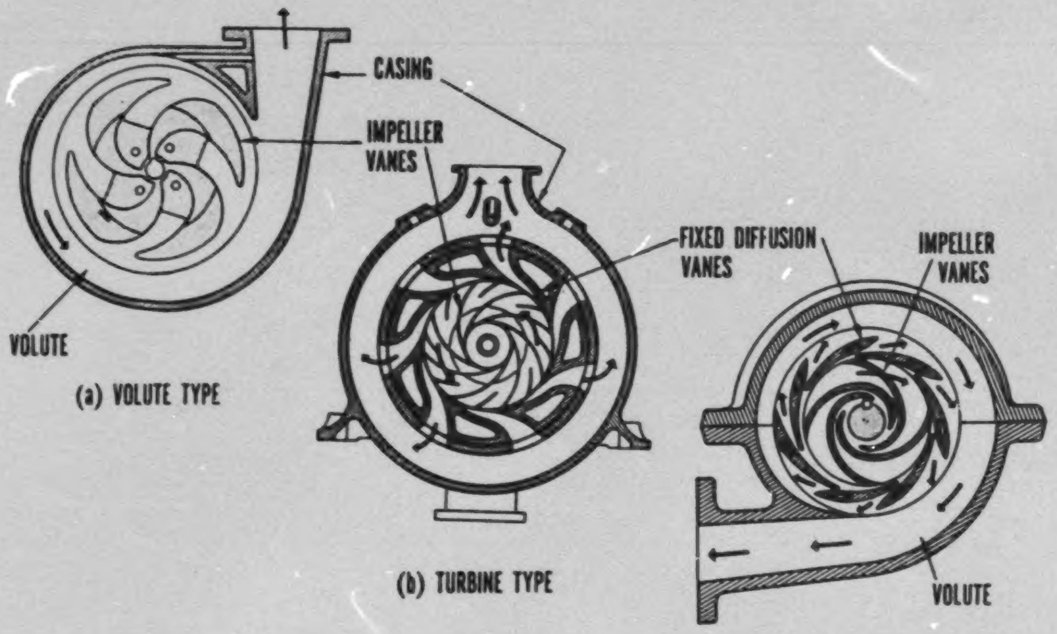
Disadvantages

1. Highly skilled workers needed for servicing and aligning.
2. Need checking more frequently because of its high speed.
3. Loss of efficiency on high or low loads.

As you can readily see, the advantages are greater than the disadvantages. That is why centrifugal pumps are so widely used as feed-water pumps today.

References: *Steam Plant Operation*
Elementary Steam Plant Engineering

Assignment:
1. How does a centrifugal pump work?
2. What factors would you consider if you were selecting a new feed-water pump?
3. Name the parts of a centrifugal pump.
4. State the advantages and disadvantages of using centrifugal pumps.



(a) VOLUTE TYPE

(b) TURBINE TYPE

(c) VOLUTE TURBINE TYPE

BASIC TYPES OF CENTRIFUGAL PUMPS

Objectives:

1. Be able to define the terms: suction lift or suction head, discharge head, and friction head.
2. Be able to calculate the total head on a centrifugal pump.
3. Be able to convert foot head to pounds per square inch.

Information: The distance that water can be raised (vertical lift) by a centrifugal pump is limited. The theoretical lift is approximately 34 feet and changes with the atmospheric pressure. When the atmospheric pressure is 14.7 p.s.i. (equivalent to about 30" on a barometer), the theoretical lift is:

$$14.7 \text{ p.s.i.} \div \frac{.433 \text{ p.s.i.}}{\text{Ft.}} = 33.9 \text{ Ft.}$$

This is not possible in practice since leaks in the suction line, packing glands, etc. reduce the actual lift to approximately 24 feet. In fact it may go as low as 10 to 15 feet because of friction loss in the suction line.

Suction lift is the vertical distance from the level of the water being pumped to the center line of pump. Suction head is the vertical distance from the center line of the pump to the surface of the water above the pump. Both suction lift and suction head are illustrated in Figure 6-E-2-M-1-1.

The discharge head is the vertical distance between the center line of the pump and the level of the water above the pump. Friction head is a loss caused by the friction of the water on piping, valves, and fittings. The total head in feet against which a pump operates equals:

1. Suction Lift + Discharge Head + Friction Head

or

2. Discharge Head + Friction Head + Suction Head

In No. 1, the pump has to lift water. In No. 2, the water level is above the center line of the pump.

Example 1: In Figure 6-E-2-M-1-2, the suction lift of a pump is 15 ft; it discharges into a tank 40 ft. above the center line of the pump against friction heat of 17 ft. Find the total head of the pump.

T. H. = S.L. + D.H. + F.H.
T. H. = 15 + 40 + 17
T. H. = 72 ft.

Example 2: Suction Head = 35 Ft.
Discharge Head = 40 Ft.
Friction Head = 17 Ft.
Find total head on the pump.

$$\text{T. H.} = \text{D. H.} + \text{F. H.} - \text{S. H.}$$
$$\text{T. H.} = 40 + 17 - 35$$
$$\text{T. H.} = 22 \text{ Ft.}$$

Example 3: In Figure 6-E-2-M-1-3, the suction head of a pump is 35 ft; it discharges into a pressure vessel 40 ft. above the center line of the pump against a friction head of 17 ft. with a pressure in the vessel of 30 p.s.i. Find the total head on the pump.

$$\text{T. H.} = \text{D. H.} + \text{F. H.} - \text{S. H.}$$
$$\text{T. H.} = (40 + 30/.433) + 17 - 35$$
$$\text{T. H.} = 40 + 69 + 17 - 35$$
$$\text{T. H.} = 91 \text{ Ft.}$$

Note: To convert pounds per square inch to foot head, divide by .433 p.s.i./ft.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Find the total head on a pump with a suction lift of 12 feet, a discharge head of 50 feet, and a friction head of 10 feet.
2. A fire pump has to fill a tank 250 feet above the pump. The loss due to friction is 25 feet, and the pump takes its suction from a city water main with a pressure 35 p.s.i. What is the total head on the pump?
3. A boiler operates at 100 p.s.i. steam pressure and is supplied with feed-water from a feed-water heater that has an internal pressure of 10 p.s.i. The boiler is located 30 feet above the pump, and the heater is 45 feet above the pump. Neglecting friction, what is the total head on the pump?

Objectives:

1. Be able to describe the purpose, location, and types of injector.
2. Be able to describe how an injector operates.
3. Be able to describe the reasons for injector failure.
4. Be able to explain the fireman's responsibility regarding feed-water injectors.

A feed-water injector is an auxiliary or secondary means of feeding water to a boiler. The package type firetube boiler usually comes equipped with an injector and an electric feed-water pump. The injector is not considered an efficient means of feeding a boiler with water. It cannot handle hot water. The maximum water temperature is 130°F to 150°F. After 150°F it will become steam bound. It can lift water a maximum of 20 feet under the best conditions. It also tends to kick out under a fluctuating steam load.

The injector should be placed close to the boiler it is feeding, and the steam line to the injector should come from as high a part of the boiler as possible to insure dry steam.

The injector works on the principle that kinetic energy is greater than potential energy. Steam passing through a nozzle drops in pressure, expands, and increases in velocity. It picks up the water, and the velocity or kinetic energy forces open the check valve discharging the water into the boiler.

There are many types of injectors. Low-pressure injectors are used for steam up to 40 pounds pressure, and high-pressure injectors are used for pressures over 40 pounds. There are single-tube and double-tube injectors. Injectors are mostly found on firetube boilers, but they can be used on smaller watertube boilers.

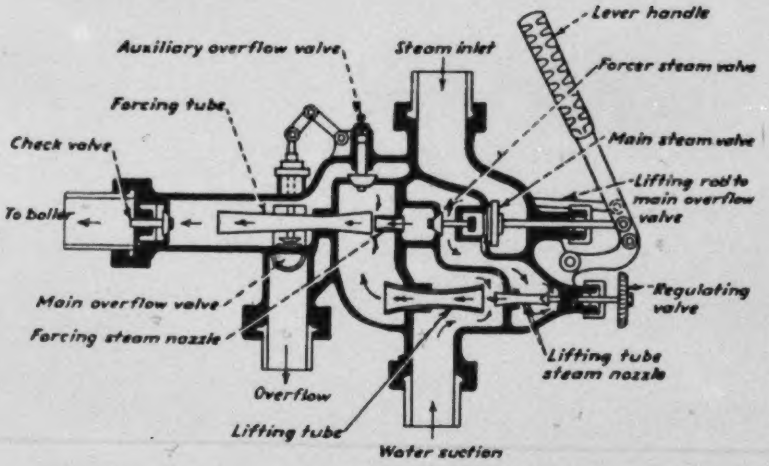
It is the fireman's responsibility not only to know where the injector is located in this plant; but he must also use it periodically to insure its operation in the event of an emergency.

If the injector is being fed by city water, there must be a check valve placed between it and the city water meter. This will prevent the meter from being damaged and the city water from being contaminated in the event the injector kicks out and the steam tries to back up into the city water line.

References: *Boiler Room Questions & Answers*
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. Discuss the purpose of an injector.
2. Do you think injectors are efficient as pumping units? Explain your answer.
3. Where should the steam line feeding the injector come from?
4. Is there any special reason for the steam line location?
5. What is the maximum water temperature an injector is capable of handling.
6. How high is the injector able to lift water?
7. List the advantages and disadvantages of an injector.
8. As a fireman, what is your responsibility towards a feed-water injector?
9. Why must the city water meter be protected by a check valve?
10. What are some of the common causes for injector failure?
11. Explain the principle of operation of a feed-water injector.
12. List the essential parts of a single-tube injector.
13. List the essential parts of a double-tube injector.


Lever handle
Auxiliary overflow valve
Steam inlet
Forcer steam valve
Forcing tube
Main steam valve
Check valve
Lifting rod to main overflow valve
To boiler
Regulating valve
Main overflow valve
Forcing steam nozzle
Lifting tube steam nozzle
Overflow
Lifting tube
Water suction

FEEDWATER INJECTOR 6-E-3

Objectives:

1. Be able to explain why careful planning and design is essential for boiler room piping.
2. Be able to explain how and why steam lines are pitched.
3. Be able to explain why we allow for expansion stresses in steam lines.

Information: The successful and economical operation of a steam power plant depends, to a large extent, upon the general arrangement of the piping system. Every engineer or fireman in steam power plant work should be familiar with the general requirements of a well-designed piping system. Before any steam apparatus can be installed, all the steam and water piping systems should be worked out in detail. All separators, valves, fittings, drip legs, etc. should be drawn to scale in their respective positions. Valves should be located in accessible positions where it is possible to reach them in a hurry. Important valves placed overhead or in inaccessible positions should be equipped with a chain wheel and chain, or a system or gearing and extension stems. The steam piping system should be well covered or lagged with a good grade of non-conducting covering material. Some water is still likely to accumulate in the system due to condensation. Therefore, the piping should contain no pockets or low spots in which water can collect. The condensed water should be returned through a system of steam traps to the boiler or feed-water heater. Water in the steam lines is a constant source of danger. An accumulation of water may be picked up by a heavy flow of steam and projected with great force against a fitting, flange, valve or sharp bend in the steam line. This could lead to a rupture or water being carried over to the engine cylinder by the flowing steam. Since we know that water cannot be compressed, water carried over to your engine might cause a blown gasket or a damaged cylinder head. It is always advisable to install a steam separator in the line before the engine throttle. This will intercept any slugs of water as well as provide a reservoir of steam close to the engine. It will absorb the shaking and jarring caused by the quick cutoff in the steam chest.

Horizontal steam pipes should always be pitched in the direction of flow. The water in the lines due to condensation or carryover will flow with and not against the direction of flow of steam. When condensation flows against the flow of steam, water hammer is likely to occur. This is why steam lines should not be carried at a slope from a lower to a higher level. The steam line should rise vertically to the desired height and then horizontally to the desired location. Care should be taken to pitch the horizontal pipe in the direction of steam flow. Drip legs and traps should be installed at the base of vertical risers to drain off water since they would tend to collect there and be carried over into the branch lines with the first heavy flow of steam.

Unless firmly anchored, the main steam header is subjected to a change in position due to expansion and contraction strains in the main steam header and the branch lines leading to and from it. In steam lines of any length, provision should be made to relieve expansion and contraction strains. Otherwise, leakage may take place and rupture may be caused at the weakest point in the main. An expansion bend of long radius should be installed in the line between the fixed points where a pipe line is anchored at any two points.

No special rule can be given for the general arrangement of steam lines in a steam power plant since the conditions to be met vary greatly. The mains should be carried as directly as possible. The piping should contain as few joints as possible; it should be designed to permit repairs being made to any disabled branch without shutting down the whole plant. The system should be protected by valves arranged so that any disabled branch of the system may be cut out of service.

In the lessons that follow, we will discuss the location, purpose, and types of equipment.

References: *Steam Plant Operation*
Elementary Steam Power Engineering
Boiler Room Questions and Answers

Assignment:

1. List five requirements of a well-designed pipeline.
2. What three methods are used to allow for expansion in a steam line?
3. List three grades of steel pipe.
4. What is insulation?
5. List some materials used for insulation purposes.
6. How should overhead valves be installed?
7. How should horizontal steam lines be pitched?
8. Why are water pockets in a steam line dangerous?
9. How is the condensate removed from steam lines?

Objectives:

1. Be able to explain why expansion must be allowed for in pipe lines.
2. Be able to calculate the amount of expansion that will take place in the lines.

Information: When water, steam, or gas at high temperatures is carried by pipes, proper provision must be made for expansion and flexibility. With the use of increased temperatures and pressures, the stresses and reactions caused by thermal expansion in piping has increased the attention given to details and methods of design.

The expansion between pipe lines can be taken up by expansion joints, swing joints, and pipe bends. The number of expansion joints installed in a pipe line depend on:

1. The amount and direction of expansion
2. The amount of expansion permitted by each joint.

The amount of expansion in piping depends upon the material from which the piping is made and the difference in temperature between the pipe when hot and when cold. The amount of expansion in inches may be calculated by the following formula:

$$\text{Expansion in Inches} = L \times C \times (T_1 - T_2) \times 12$$

L = Length of pipe in feet
C = Coefficient of linear expansion per inch of length per degree F
T_1 = Final temperature in degrees F
T_2 = Initial temperature in degree F

Coefficient of linear expansion per inch for:

Bronze = .00001111
Wrought Iron = .0000068
Steel = .0000067
Cast Iron = .0000065

Example: A steel pipe 293′ long carries steam at 190 p.s.i.a. and is superheated to 125°F. Find the theoretical amount of expansion when heated from a room temperature of 80°F.

Expansion in inches = $L \times C \times (T_1 - T_2) \times 12$

$293 \times .0000067 \times (502.6 - 80) \times 12$

Note: Temp. of steam at 190 p.s.i.a. = 377.6
377.6 + temp. of superheat 125 = 502.6 = 9.95 inches

Note: If temperature of steam is not given, check steam tables.
Remember it is absolute pressure.

References: *Boiler Room Questions and Answers*
Elementary Steam Power Plant Engineering

Assignment:

1. A cast iron pipe 175′ long carries steam at 100 p.s.i.a. and is being heated from a room temperature of 75°F. Find the amount of expansion.
2. A steel pipe 300′ long carries 500 p.s.i.a. and is superheated to 250°F. Find the amount of expansion from an outside temperature of 60°F.
3. What would be the amount of expansion in a steel steam pipe 350′ long if the room temperature is 90°F and the steam pressure is 155 p.s.i.?
4. A steam pipe of wrought iron is 185′ long. It carries a pressure of 285 p.s.i. The outside temperature is 90°F. Find the amount of expansion.
5. What is the amount of expansion in a cast iron water line 425′ long carrying 195°F water with an outside temperature of 50°F?
6. What is the amount of expansion on a cast iron header 40′ long. carrying 20 p.s.i.a. steam with a boiler room temperature of 85°F.
7. A steel header carries 250 p.s.i.a. and is superheated to 185°F. It is 80′ long and the boiler room temperature is 80°F in the winter and 130°F in the simmer.

   Find: a. Expansion in summer.

   b. Expansion in winter.

Objectives:

1. Be able to locate and to explain the purpose of the main steam stop and automatic non-return valves.
2. Be able to explain the fireman's responsibility toward the main stop and automatic non-return valves.

Information: The A.S.M.E. Code states that high-pressure boilers in battery that are equipped with manhole openings must have two main steam stop valves with an ample free-blowing drain between them. It further states that these valves should be of the O. S. & Y. type that will show by the position of its spindle whether it is open or closed. The valve should be a gate valve since it offers no resistance to the flow of steam; it should always be wide open or completely closed. You may use an automatic non-return valve in place of a one-stop valve, but it must be located as close to the shell of the boiler as practical. The main stop valve is used to place a boiler in service or isolate it from the system for cleaning, inspection, or boiler repairs. The automatic non-return valves improve the safety and more efficient operation of the plant. It can cut a boiler in on the line automatically and protect the system in the event of a failure on the pressure side of any boiler on the line. If a boiler dropped some tubes and the pressure in the boiler dropped below header pressure, the non-return valve would close taking the boiler off the line and preventing steam from backing out of the other boiler. Both the main stop valve and the automatic non-return valve should be dismantled, inspected, and overhauled annually.

In order to cut a boiler in on a line that is equipped with an automatic non-return valve, you would proceed as follows:

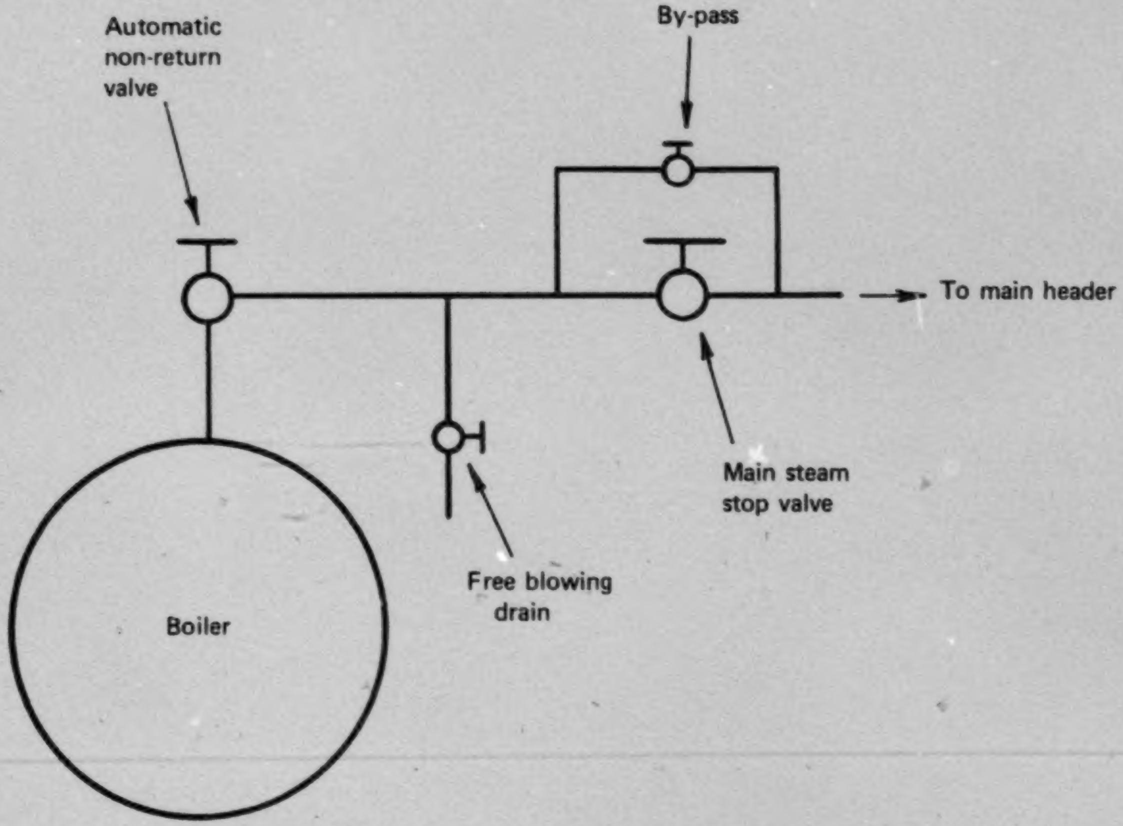
1. After making all necessary safety checks and warming up the boiler slowly, you would open the bypass around the main steam stop valve to warm up valve and equalize pressure on both sides of valve. See Figure 7-B-1-1.
2. When you have about 85% of the line pressure on the incoming boiler, slowly open main steam stop valve.
3. Open free-blowing drain to remove any condensate trapped between the two valves.
4. Open automatic non-return valve.
5. Slowly bring up pressure of incoming boiler to line pressure, and let automatic non-return valve cut boiler in on line.
6. Close free-blowing drain. The automatic non-return valve will start to open when the pressure of the incoming boiler is one pound higher than line pressure.

If you had two hand-operated valves, you would follow steps 1, 2, and 3; then when pressure of incoming boiler was about 5 pounds below header pressure, you would slowly crack open main stop valve closest to the shell of the boiler. The header pressure, being a little higher than the incoming boiler pressure, would force any trapped condensate in the line back into the boiler; it also prevents carryover.

References: *A.S.M.E. Code,* Section I
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. List the number of valves required on the boiler main steam line.
2. What is meant by an O.S. & Y. valve?
3. Why are gate valves recommended for main steam stop valves?
4. Where must the automatic non-return valve be located?
5. What purpose does the bypass valve around the main stop valve serve?
6. What is the function of an automatic non-return valve?
7. Describe in detail how you would cut a boiler in on the line if it were equipped with an automatic non-return valve.
8. If your boiler were equipped with two hand-operated main steam stop valves, and you were cutting the boiler in on the line, would you open the stop valve when the boiler was equal to, less than, or greater than line pressure? why?


Automatic non-return valve
By-pass
To main header
Main steam stop valve
Free blowing drain
Boiler

A.S.M.E. CODE SUGGESTED PIPING FOR BOILER STOP VALVES 7-B-1-1

Objectives:

1. Be able to locate and to explain the purpose of pressure regulators.
2. Be able to explain how a pressure regulator functions.

Information: In the modern industrial plant of today, there is a continuing demand for higher steam pressures to run prime movers at greater efficiencies. Steam plant auxiliaries and heating systems do not need this high-pressure steam from the main headers, so steam pressure reducing valves are used to lower it. The basic regulator consists of a balanced valve with a diaphragm attached to a stem. A spring under tension opens the valve, and steam pressure on the diaphragm from the down stream side of the valve tends to close it. See Figure 7-B-2-1.

Good practice dictates that whenever a pressure reducing valve is installed, stop valves and a bypass valve should be used in conjunction with it. This is to prevent a shutdown of the system in the event of regulator failure.

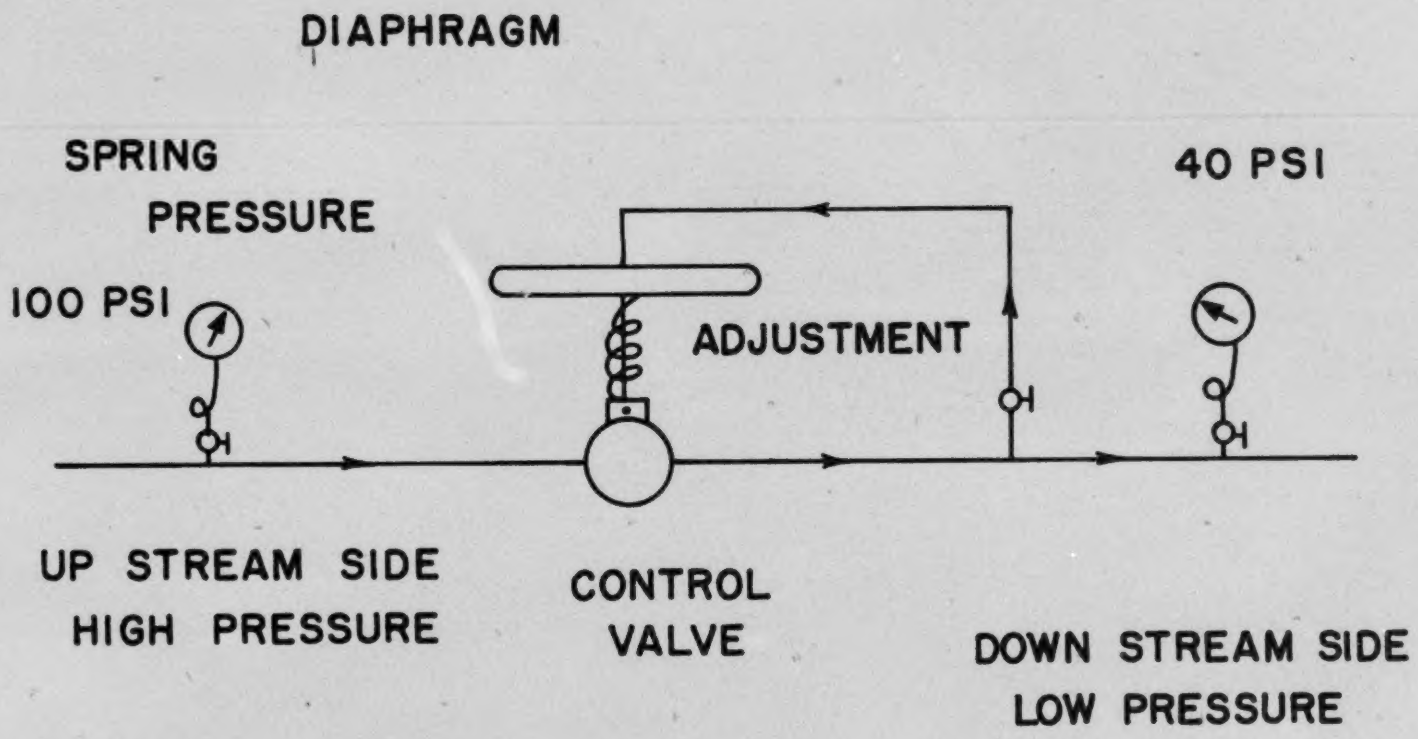
Steam that is reduced in pressure through a reducing valve will be superheated steam on the low-pressure side.

References:

Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. What is the purpose of a pressure-regulating valve?
2. Where would you expect to use a reducing valve?
3. Explain in your own words how a pressure regulator operates.
4. Why do you think the steam after the regulator is superheated?



DIAPHRAGM

SPRING PRESSURE

100 PSI

ADJUSTMENT

40 PSI

UP STREAM SIDE
HIGH PRESSURE

CONTROL
VALVE

DOWN STREAM SIDE
LOW PRESSURE

SCHEMATIC PRESSURE REDUCING VALVE

7-B-2

Non-Return Traps — Assignment 7-C-1

Objectives:

1. Be able to locate and to explain the purpose of steam traps.
2. Be able to explain the importance of trap maintenance.

Information: A steam trap is an automatic device that will increase the overall efficiency of your plant by removing air and water from the steam lines without the loss of steam. As you already know, it takes one pound of water to make one pound of steam. As the steam gives up its heat, it starts to condense, or turn back into water. This water must be removed from the steam lines because it causes water hammer and could pick this water up. When the steam line dead ends or makes a 90° turn, it could slam the water against the line and could blow the line out. A steam trap that is stuck closed will lead to a water-logged line. A steam trap that is stuck open will cause steam to blow through. If steam were allowed to enter your return lines, it could result in a loss of plant efficiency. The boilers could be working harder and the feed-water pump might become steam bound.

Steam traps are often neglected in both high-and low-pressure plants. Set up a maintenance schedule to check each trap for proper operation at regular intervals. The strainer located before traps must be kept clean to insure proper trap operation. Traps will be found on your main headers, on main branch lines, and wherever a steam line makes a 90° turn going up and on any piece of equipment that uses the heat of steam for heating or process work. Know where the traps are located in your plant. Maintain them, and make them work for you. They can save you time and money.

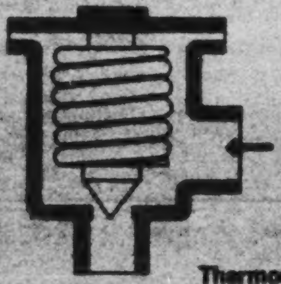
References:

Steam Plant Operation
Elementary Steam Power Engineering
Boiler Room Questions and Answers

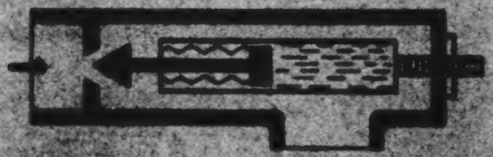
Assignment:

1. What is the purpose of a steam trap?
2. List at least five steam traps of the non-return type, and describe them briefly.
3. Where are steam traps located in a boiler room?
4. What do we mean by a non-return trap?
5. What do we mean by a return trap?
6. What is a steam strainer?
7. Why is a steam strainer used in conjunction with a steam trap?
8. Where would a steam strainer be located in a steam line?
9. What effects would a steam trap stuck open have on a system?
10. What effects would a steam trap stuck closed have on a system?

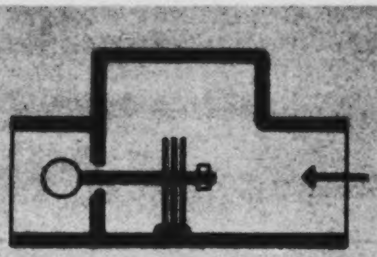
type



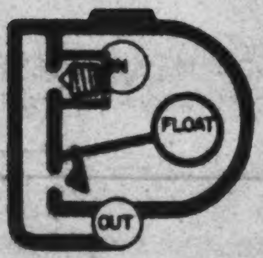
Balanced-Pressure Thermostatic Traps



Liquid-Expansion Thermostatic Traps

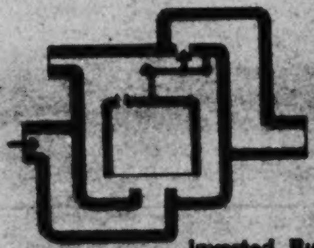


Bi-Metal Traps

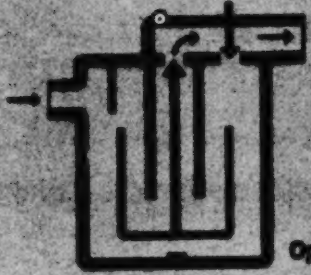


Float-and-Thermostatic Traps

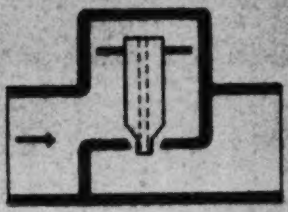
type



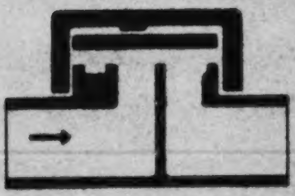
Inverted Bucket Traps



Open-Bucket Traps



Impulse Traps



Thermo-Dynamic Traps

7-C-1-2

Objectives:

1. Be able to locate and to explain the purpose of steam and exhaust separators.
2. Be able to explain the operator's responsibility regarding separators.

Information: Steam separators are found in the steam and water drums of some watertube boilers and on steam lines. They all work on the same basic principle of changing the direction of flow of the steam causing the heavier particles of water to settle out. The purposes of live steam separation are:

1. To conserve the energy of the steam.
2. To prevent wrecking of engines by slugs of water which might be present with the steam supply.
3. To prevent impairment of engine lubrication by wet steam.
4. To protect valves, pistons, and cylinders of reciprocating engines, and the blades and buckets of turbines from the erosive action of wet steam.

The receiver separator is used mainly in plants using reciprocating engines. It differs from a live steam separator because it has a large well. The well serves both as a receptacle to hold water that is extracted from the steam and as a reservoir to store a volume of steam for the engine. The steam storage capacity of a receiver separator serves three purposes:

1. Prevents vibration due to cutoff.
2. Prevents pressure drop from boiler to engine.
3. Prevents danger of slugs of water entering engine.

An exhaust separator, also referred to as an oil separator, is found on the exhaust line in plants using reciprocating engines and pumps.

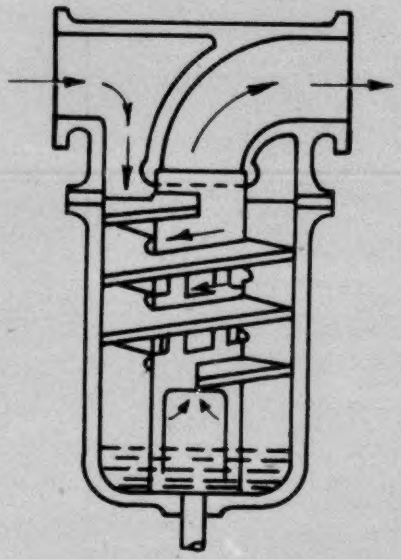
The purpose of an exhaust separator is to remove any oil in the exhaust steam. This steam may now be used in heating systems or discharged back to the feed-water heater or even the atmosphere. The oil gets into the exhaust steam as a result of cylinder oil being introduced into the steam chest of both engines and pumps. All separators work on the principle that changing the direction of flow of steam will cause water or oil to drop out. It should be noted that the water from a live steam separator or a receiver separator is trapped and returned to the feed-water system to be reused. The oil from an exhaust separator goes to waste.

Remember, a trap traps steam and allows water and air to pass through. A separator traps water and allows steam to pass through. They both work automatically, and they both increase overall efficiency of the plant. The operating engineer should keep a close watch on the separators in his plant. They are usually equipped with a sight glass. If the trap on the separator is not functioning, the separator will become waterlogged, and your equipment will suffer serious damage.

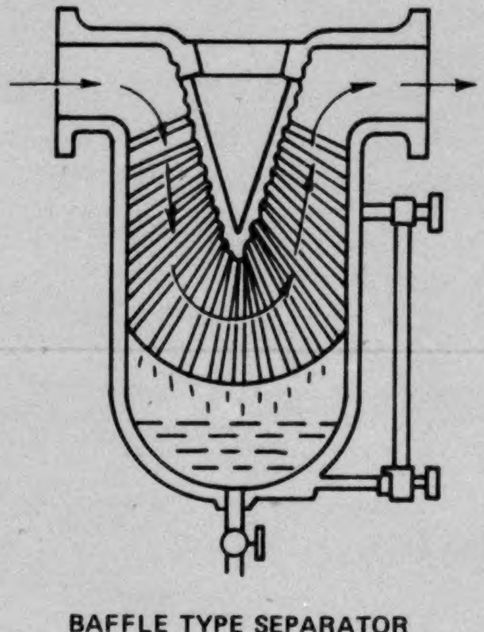
References: *Steam Plant Operation*
Elementary Steam Power Engineering
Boiler Room Questions and Answers

Assignment:

1. What is the purpose of a live steam separator?
2. Where are steam separators located?
3. List two types of steam separators, and describe how each type works.
4. List the four chief purposes of live steam separation.
5. What percentage of entrained moisture does the steam delivered by a boiler without a superheating surface ordinarily contain?
6. What is a receiver separator, and where is it found?
7. List three functions performed by a receiver separator.
8. What is an exhaust separator, and where is it found?
9. List the main purposes of an exhaust separator.
10. What danger is there in carrying slugs of water over into a steam line to the following equipment:
    - a. Steam header
    - b. Reciprocating engine
    - c. Turbine
    - d. Reciprocating pump
    - e. Centrifugal pump – electric drive



CENTRIFUGAL TYPE SEPARATOR



BAFFLE TYPE SEPARATOR

7-D-1-1

Objective: 1. Be able to calculate the efficiency of a live steam separator.

Information: We can use the following formula to find the percent efficiency of a live steam separator:

$$E = \frac{100W_W}{W_L}$$

where:

E = Per cent efficiency
W_W = Weight of separated water in pounds
W_L = Weight of moisture, in pounds, in a definite weight of steam delivered to the separator as determined by calorimeter.

Example: A steam flow meter records a flow of 16,273 pounds of steam. The quality of the steam is 94.5%. The weight of the separated water is 530 pounds. What is the efficiency of the separator?

Solution: $$E = \frac{100 \times W_W}{W_L}$$

$$W_L = 16273 \times (1 - .945) = 895 \text{ pounds}$$

$$E = \frac{100 \times 530}{895}$$

$$E = 59.2\%$$

Assignment: Using the formula above, solve the following problems:

1. Steam passing to a separator has a quality of 93%. If 5600 pounds pass per hour and the separator collects 285 pounds of water, what is the efficiency of the separator?
2. The steam flow meter records a flow of 20,000 pounds of steam per hour. The quality of the steam is 97%. The weight is 340 pounds. What is the efficiency of the separator?
3. The steam flow meter records a flow of 16,273 pounds of steam. The quality of the steam is 94.5%. The separator is said to be 59.2% efficient. How many pounds of water should be removed from the steam?
4. Steam passing to a separator has a quality of 93%. The separator is passing 5600 pounds of steam per hour. The efficiency of the separator is 72.7%. How many pounds of water will be removed?
5. A steam separator is said to be 59.2% efficient. The quality of the steam is 94.5%. The weight of the separated steam is 530 pounds. How many pounds of steam will pass the separator with the above conditions?

6. Steam passing to a separator has a quality of 93%. The separator collects 285 pounds of water and is 72.7% efficient. How many pounds of steam per hour will pass through the separator?

Objective: 1. Be able to locate and to explain the purpose of a dry pipe and cyclone separator in saturated steam drums.

Information: When a steam boiler is operated at high loads or with a high water level, there is a tendency to carry particles of water with the steam. One method used to control this carryover is to use a dry pipe and baffles.

A dry pipe consists of a pipe that runs the length of the boiler drum and is closed at both ends. The top half is drilled with many small holes, and it is connected at the top center to the main steam outlet from the boiler. It has a drain on the bottom that allows the entrained moisture to return to boiler drum.

The operation of the dry pipe is based on the principle of a separator. Steam enters the small holes on top. The steam has to change direction to leave through the steam outlet. This changing of direction causes any entrained moisture to be separated and returned to the boiler through the drain.

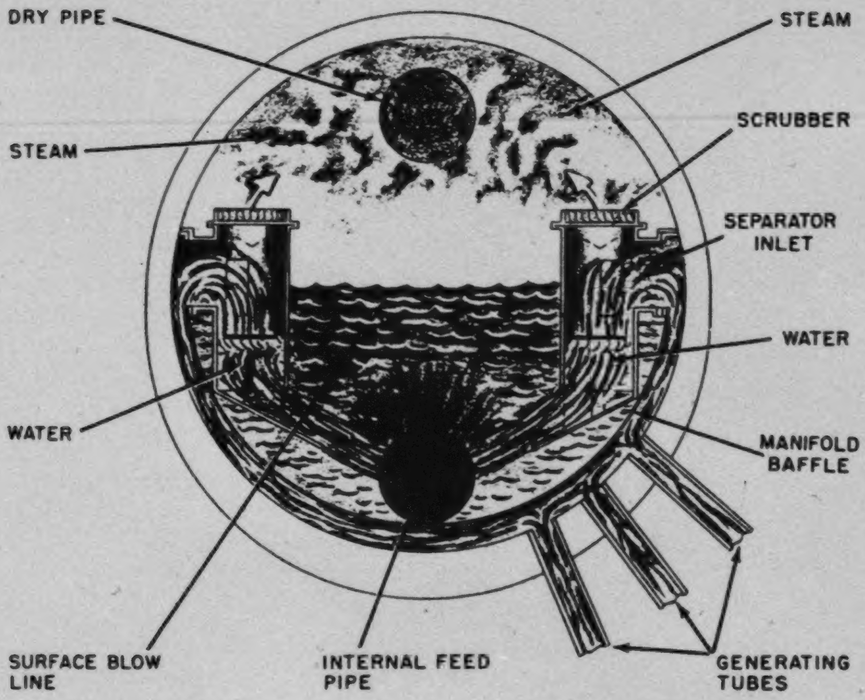
The dry pipe is very effective for small boilers or boilers with light steam loads. As the capacity of a boiler increases, it becomes less satisfactory.

The cyclose separator was developed to overcome the shortcomings of the dry pipe. It consists of a number of cyclones (somewhat like cylinders) set side by side, along the length of the drum and a baffle arrangement to direct the steam into the cyclone. Moisture is removed by centrifugal force as the steam is forced to rotate when it passes through the cyclones. For an even better separation of steam and moisture, baffles are set up over the top of each cyclone.

Steam drum separators of this type are essential when a boiler has a superheater, and it is necessary to keep carryover to a minimum.

Reference: *Steam Plant Operation*

Assignment:
1. What is a dry pipe?
2. What is a cyclone separator?
3. Where are the dry pipe and the cyclone separator located in the boiler?
4. How does each type of separator function?
5. What effect do these separators have on the quality of the steam?


DRY PIPE
STEAM
SCRUBBER
STEAM
SEPARATOR INLET
WATER
WATER
MANIFOLD BAFFLE
SURFACE BLOW LINE
INTERNAL FEED PIPE
GENERATING TUBES

7-D-2-1

Objectives:

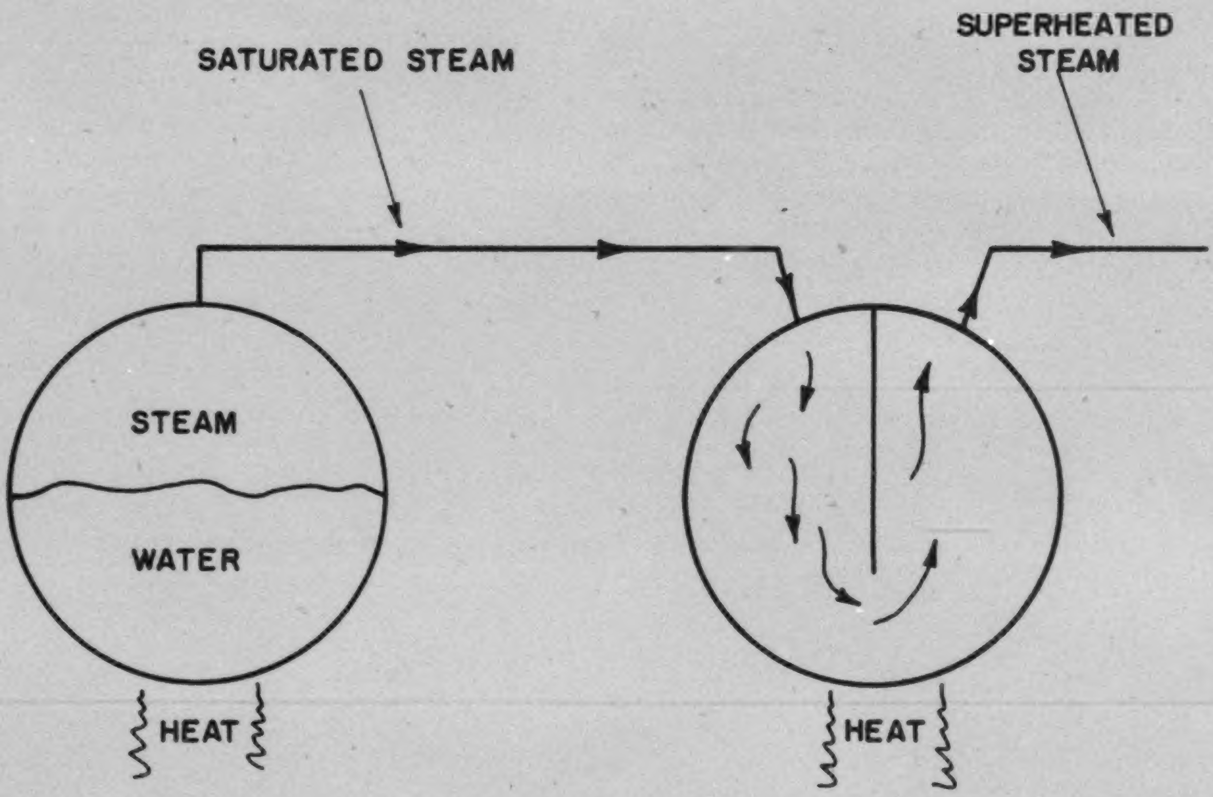
1. Be able to explain the difference between saturated and superheated steam.
2. Be able to explain why superheated steam is used.
3. Be able to explain how superheaters are protected during operation and warm up.

Information: Superheated steam has a higher heat content than saturated steam, so it can produce more work. Let's stop here a minute and go over some terminology:

1. Heat is energy.
2. Energy is the ability to do work.
3. Saturated steam is steam at its corresponding temperature and pressure.
4. Superheated steam is steam at a higher temperature than its corresponding pressure.

For example, 100 pounds of steam p.s.i.g. has a temperature of about 338°F; this is saturated steam. If we raise the temperature of this steam to 400°F or 500°F, we have raised its temperature above its corresponding pressure; and it is now superheated steam. Saturated steam is just barely steam. It will start to condense or turn back to water with any loss in temperature. Superheated steam will not condense as fast because it has a higher temperature. It can be transmitted longer distances without a buildup of condensation. This reduces radiant heat loss in piping and prime movers; it reduces erosion of turbine blades; and it will increase plant capacity.

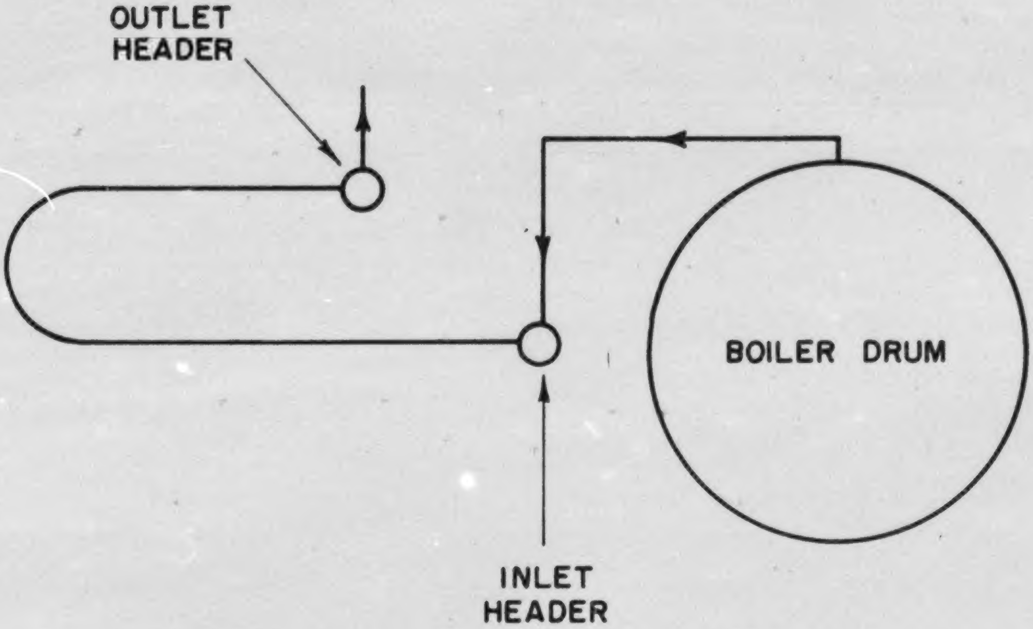
Superheaters are nests of tubes located in the direct path of the gases of combustion. They may be innerdeck or outerdeck. Superheaters must be equipped with a safety valve on its outlet header. This safety valve must be set to pop before the main safety to insure a flow of steam through the superheater. This prevents it from warping or burning out. Superheaters must also be fitted with a drain on the outlet side. This drain remains open when warming up a boiler and is left open until the boiler is cut in on the line. The drain must also be open as soon as the boiler is taken off the line. This will insure a flow of steam through the superheater at all times. This flow of steam is the only thing that keeps the superheater tubes from warping or burning out. Now we must briefly discuss the construction, function, and maintenance that they require. First, let's just look at the simple superheater in Figure 7-E-1-1.


SATURATED STEAM
SUPERHEATED STEAM
STEAM
WATER
HEAT
HEAT

7-E-1-1

In the beginning, steampower plants using reciprocating engines were designed to operate with saturated steam. Steam separators were introduced between the boiler and engine to remove condensate from the steam to improve the quality of the steam. Definite drawbacks to using this wet steam were corrosion of pipes, erosion of engine parts, pipes and fittings caused by impingement of the steam, and loss of heat to metal causing condensation of steam. These drawbacks were almost eliminated by using superheated steam. It should be noted that in an average steam turbine there is a gain of 1% in efficiency for every 35°F of superheat. The increase can go as high as 15% for 200°F of superheat in larger turbines.

Superheaters are of two general types – smooth and extended surface. Extended surface superheaters have cast-iron fins or grills shrunk upon a smooth tube which increases the heating surface. They are in many forms and shapes because of the difference in boiler size and design and available space for its location in the boiler. Below is a sketch of a smooth-tube hairpin type of superheater that is located overdeck.



7-E-1-2

The multi-loop superheater consists of many tubes bent back on itself a number of times between the inlet and outlet headers.

Modern practice tries to place the superheater headers outside the boiler. This makes them easily accessible, and it removes the tube and header connections from the high temperature zones. The tube elements are bent at a constant radius, and the bends at one end are drop-forged. Tubes of this type are connected to the header by detachable metal-to-metal ball joints secured by heat treated steel studs and clamps. Any joint can be broken by removing the nut that holds the clamp unit. This would tend to make repairs easier. Superheaters must be kept free of soot to improve the transfer of heat.

References: *Steam Operation*
Elementary Steam Power Engineering

Assignment:

1. Define the following:
    a. Heat
    b. Energy
    c. Saturated steam
    d. Superheated steam
2. List the two general types of superheaters.
3. How can a constant superheater temperature be secured?
4. Why must a superheater be fitted with a safety valve?
5. Does the superheater safety pop before or after the main safety? Explain why.
6. Why are superheaters equipped with drains, and how are these drains handled?
7. List some of the advantages of using superheated steam.
8. If boiler rating is increased, what is the effect on superheater temperature with a convection type superheater? With a radiant type superheater?

Objectives:

1. Be able to locate and to explain the purpose of two types of desuperheaters.
2. Be able to explain the operator's responsibility regarding desuperheaters.

Information: To some people, it may sound foolish to desuperheat the steam after you went through the trouble of superheating it. It's like watching a person make iced tea. First, boil it to make it hot; then add ice to make it cold. Add sugar to make it sweet; then put lemon in it to make it sour. It should be understood that the auxiliaries are not designed to use high degrees of superheat. The prime movers, mainly turbines, are designed and need superheated steam for maximum efficiency. It is not practical to have one boiler supply superheated steam and another, saturated steam. It is much easier to draw off some superheated steam, desuperheat it, and then send it to the auxiliaries. The superheater also serves to insure a flow of steam through the superheater at all times. This lessens the danger of overheated or burned out tubes.

One method of desuperheating the steam is to bring the steam back to the steam and water drum of the boiler; then pass it through coils of submerged piping. This coil is a desuperheater. The superheated steam gives up its superheat to the boiler water which is at the saturation temperature. It leaves the boiler at or near the saturated steam temperature. It is known as the drum type.

Another type of desuperheater is a spray or line type. There is a chamber fitted with one or more nozzles. They deliver a fine spray of water into the steam, thus reducing its temperature. A thermostat is placed in the line on the saturated steam side of the desuperheater. This will control the water supply to the steam spray. If the temperature rises, more water will be introduced into the steam line. If the temperature falls, the water will be reduced thus maintaining the temperature desired. It should be evident that these spray nozzles must be inspected and kept free and clear, so that this type of desuperheater will work.

References:

Steam Plant Operation
Boiler Room Questions and Answers
Elementary Steam Power Engineering

Assignment:

1. What is the purpose of a desuperheater?
2. List two types of desuperheaters.
3. Why is it necessary to desuperheat the steam?
4. Describe how a spray type desuperheater works.
5. From your observations, which type of desuperheater would be more efficient?
6. What maintenance would a spray type desuperheater require?
7. Define:
   - a. Saturated steam
   - b. Superheated steam
   - c. Desuperheated steam

Origin of Coal, Oil and Gas — Assignment 8-A-1

Objective: 1. Be able to explain the origin of coal, oil, and gas.

Information: Coal is referred to as a fossil fuel. It is the result of the decomposition of the lush tropic vegetation of prehistoric forests. Hugh trees and ferns grew in a hot, humid climate. Layer upon layer of partly decomposed trees and vegetation was covered with sediment, sand, and water. Millions of years of pressure and heat converted the plant carbohydrates to hydrocarbons, or coal. The geologists say temperature, time, and pressure are the factors necessary to change the wood and vegetation to peat, which was then changed to coal. Chemists insist that microorganisms also were an important added factor. There are many different opinions of how this all took place and how long it took. For example, some claim that it took about 20 feet of plant matter to form 1 foot of soft coal. Others say it took 100 years to form 1 foot of peat; and it took 4 feet of peat to form 1 foot of coal. But, they do agree on where coal came from. It is a natural chemical process where plant life absorbs carbon dioxide from the atmosphere. Then, with the aid of sunlight and moisture, it converts these ingredients to carbon, hydrogen, and oxygen; these carbohydrates are the basis of coal.

There are several theories on the origin of fuel oil. Some believe that it is the result of animal or vegetable matter that decayed and aged under pressure in the presence of salt water. Others feel that is was formed by inorganic substances by the action of minerals, and gases. It was at one time very abundant in this country; and it was cheap enough to use as fuel in the generation of steam.

Crude oil, as it comes from the ground, is usually sent to a refinery. Through the process of distillation, the various gases, kerosene, and grades of oil are produced.

Natural gas is usually found in the same place as petroleum. It is felt that they have the same origin because they are found together. They were formed under pressure and trapped in shale formations and porous rock or cavities. Then, they were sealed by layers of non-porous or close-textured rock.

References:
Steam Plant Operation
Elementary Steam Power Engineering
Combustion Engineering

Assignment:

1. Where did coal come from?
2. What factors were involved in the formation of coal. List them in the order of their importance according to you.
3. What determines the characteristics of coal?
4. What are the two theories on the origin of oil?
5. Can crude oil from the well be burned as is?
6. If crude oil can be burned as is, are there any precautions to follow?
7. Where does natural gas come from?
8. How is it removed from the ground?

Objectives:

1. Be able to explain how oil is classified.
2. Be able to explain what is meant by B.t.u. content.

Information: We don't use petroleum directly from the oil wells for our oil burners or for our automobiles. The petroleum must be distilled first. But did you know that petroleum from California and Texas oil wells is distilled into fuel oil, and that petroleum from mid-western U.S. oil wells is not distilled into fuel oil. There is a reason.

Petroleum is classified in several ways. Usually it is classified by the base it will yield after it is distilled. So, we end up with petroleum that has (1) a paraffin base, (2) an asphalt base, or (3) an olefin base. The paraffin base oil comes from the mid-west; it yields valuable light oils that are not often used as fuel. Asphalt base oil from California and Texas is used for fuel. There is also an olefin base oil from Russia that is also used for fuel. So, you can see that petroleum from different areas has different characteristics.

Crude oil from the well is distilled into individual products such as gasoline, diesel fuel, lubricating oils, and heating fuels. For example, the distillate oil used for the lighter grades of oil is produced by fractional distillation; it has a consistency between kerosene and lubricating oil. Blended oils are produced by mixing oil to certain specifications. Residual oil is produced by removing hydrocarbons. After hydrocarbons have been removed, the flash point is lower, and the residual oil can be safely stored and burned.

Fuel oil is also classified by grades of No. 1, No. 2, No. 3, No. 4, No. 5, and No. 6. This chart will help you recognize them.

	No. 1 Fuel Oil	No. 2 Fuel Oil	No. 4 Fuel Oil	No. 5 Fuel Oil	No. 6 Fuel Oil
Type	Distillate Kerosene	Distillate	Very light Residual	Light Residual	Residual
Color	Light	Amber	Black	Black	Black
A.P.I. 60°F	40	32	21	17	12
Specific Gravity	.8250	.8654	.9279	.9529	.9861
Lbs/U.S. Gal.	6.87	7.206	7.727	7.935	8.212
B.t.u./Gal.	137,000	141,000	146,000	148,000	150,000

The heating value of fuel oil is expressed in B.t.u.'s per pound or B.t.u.'s per gallon. The B.t.u. rating of a fuel indicates how much heat it produces. Heavier oils contain more B.t.u.'s than lighter oils, so the specific gravity of fuel oils is used in calculating heating value. Heating value is determined by:

$$\text{B.t.u. 1 lb.} = 17780 + (54 \times \text{Degrees A.P.I.})$$

Specific gravity of oil is defined as: "the ratio of the weight of any volume of oil at 60°F to the weight of an equal volume of water at 60°F. It is designated as Sp. Gr. 60/60F and is carried to four decimal places. A hydrometer is used to measure specific gravity. It is read direct or expressed in degrees A.P.I. (American Petroleum Institute). The relationship between specific gravity and degrees A.P.I. is found as follows:

$$\text{Sp. Gr. 60/60F} = \frac{141.5}{131.5 + \text{Degrees A.P.I.}}$$

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{Sp. Gr. 60/60F}} - 131.5$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. How is petroleum classified?
2. What is residual oil?
3. Why aren't paraffin base oils used for fuel oil?
4. Using the chart of the grades of oil answer the following:
    As the B.t.u. content goes up what happens to the specific gravity?
5. Define specific gravity.
6. How is the specific gravity determined?
7. How is the heating value of fuel oil expressed?

Objectives:

1. Be able to convert specific gravity to degrees A.P.I.
2. Be able to convert degrees A.P.I. to specific gravity.

Information: In the last assignment, we learned that specific gravity is the ratio of the weight of any volume of oil at 60°F to the weight of an equal amount of water at 60°F. It is carried to four decimal places and is expressed as:

Sp. Gr. 60/60F

When we know the degrees A.P.I., the formula for determining the specific gravity of the fuel oil (Sp. Gr. 60/60F) is:

$$\text{SP. Gr. } 60/60\text{F} = \frac{141.5}{131.5 + \text{degrees A.P.I.}}$$

For example, find the specific gravity of fuel oil that is 40° A.P.I.

$$\text{Sp. Gr. } 60/60\text{F} = \frac{141.5}{131.5 + \text{degrees A.P.I.}}$$

$$\text{Sp. Gr. } 60/60\text{F} = \frac{141.5}{131.5 + 40}$$

$$\text{Sp. Gr. } 60/60\text{F} = \frac{141.5}{171.5}$$

$$\text{Sp. Gr. } 60/60\text{F} = .8250$$

When we know the Sp. Gr. 60/60F, the formula for determining degrees A.P.I. is:

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{Sp. Gr. } 60/60\text{F}} - 131.5$$

For example, find the degrees A.P.I. when the specific gravity of the fuel oil is .9930.

$$\text{Degrees A.P.I.} = \frac{141.5}{.9930} - 131.5$$

$$\text{Degrees A.P.I.} = 142.5 - 131.5$$

$$\text{Degrees A.P.I.} = 11$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment: Find the missing degrees A.P.I. and the missing Sp. Gr. 60/60F in the chart below:

	Degrees A.P.I.	Sp. Gr. 60/60F
1.	3	?
2.	?	1.0366
3.	8	?
4.	?	1.0071
5.	11	?
6.	?	.9792
7.	14	?
8.	?	.9465
9.	19	?
10.	?	.9340

Properties of Oil

Assignment 8-B-2

Objectives: 1. Be able to describe the properties of fuel oil.

Information: Fuel oil consists mainly of carbon and hydrogen with some moisture, sulphur, nitrogen, arsenic, phosphorus, and silt. The sulphur content of the oil is controlled by law in New Jersey. This was done to cut down on sulphur dioxide in the flue gases which contaminated the air.

The fireman and engineer must be familiar with the characteristics of a fuel oil in order to safely handle it. Let's look at a few points to remember:

Viscosity: Oil's internal resistance to flow. We raise the oil's temperature to lower its viscosity making it easier to be pumped.

Flash point: Temperature at which oil will give off a vapor that will flash when exposed to an open flame. A fuel oil with a low flash point would be dangerous to use.

Fire point: Temperature at which oil will give off a vapor that will burn continually.

Pour point: Temperature at which oil will no longer flow as a liquid.

Heating value: Expressed in B.t.u.'s per pound or B.t.u.'s per gallon.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Define the following:
    a. Viscosity
    b. Flash point
    c. Fire point
    d. Pour point
2. What disadvantages if any are there in using a fuel oil with a low flash point?
3. How is the heating value of oil expressed?
4. How can you lower the viscosity of a fuel oil?
5. What would happen if you had a fuel oil with the pour point of 100°F and the temperature in the fuel tank dropped to 80°F?

6. Discuss the advantages of using oil over coal.
7. What are the disadvantages of burning oil?
8. What difficulties will the following cause:
    a. Abrasive particles in oil.
    b. Sulphur in oil.
    c. Moisture and sludge in oil.

B.t.u. Content Per Pound of Fuel Oil — Assignment 8-B-2-M1

Objective: 1. Be able to calculate the B.t.u. content of fuel oil when its degrees A.P.I. are known.

Information: If you know the degrees A.P.I. of a fuel oil, you can find the approximate B.t.u. content per pound by using the following formula:

B.t.u./Pound of Oil = 17,780 + (54 × degrees A.P.I.)

Example: Fuel has specific gravity of 10 degrees A.P.I. Find B.t.u. content per pound of oil.

B.t.u. 1 lb. = 17,780 + (54 × degrees A.P.I.)
= 17.780 + (54 × 10)
= 17,780 + (540)
= 18,320

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment: Find B.t.u. content per pound and per gallon for the following:

	Degrees A.P.I.	Lb./Gal.	B.t.u./Lb.	B.t.u./Gal.
1.	3	8.762		
2.	5	8.634		
3.	9	8.388		
4.	11	8.270		
5.	12	8.212		
6.	15	8.044		
7.	18	7.882		
8.	20	7.778		

Classification of Coal — Assignment 8-C-1

Objectives:

1. Be able to describe how coal is classified.
2. Be able to define rank and grade.
3. Be able to define B.t.u. content.

Information: Coal is still the most important fuel used for steam generation. Some basic facts should be understood in order to determine the suitability of coal for a given installation.

Coal is the result of a natural chemical process. Plants absorb carbon dioxide from the atmosphere. Under the influence of sunlight, moisture, and heat, they turn it into carbon, hydrogen, and oxygen. These conditions vary, so the end product coal, varies and must be classified. It is classified according to rank and grade. Rank refers to the degree of hardness, and grade refers to size, heating value, ash content, etc.

Classification of coal by rank:

1. Peat
2. Lignite
3. Subbituminous
4. Bituminous
5. Semibituminous
6. Subanthracite
7. Anthracite

Classification of coal by grade (commercial sizes)

Bituminous	
Run of mine	8"
Lump	5"
Egg	5" × 2"
Nut	2" × 1¼"
Stroker	1¼" × ¾"
Slack	¾" and under
Anthracite	
Broken	
Egg	
Stove	
Nut	
Pea	
Buckwheat	
Rice	
Barley	

In order to further classify coal as to heating value and ash content etc., we must use an approximate analysis and an ultimate analysis. It is the ultimate analysis that will allow us to figure the B.t.u. content of coal per pound by using DuLong's formula.

$$\text{B.t.u.'s/lb.} = 14{,}540C + 62{,}000\,(H - 0/8) + 4050S$$

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. How is coal classified?
2. What does each classification show?
3. Discuss the commercial sizes of bituminous coal
4. Discuss the commercial sizes of anthracite coal.
5. What is meant by hard coal?
6. What is meant by soft coal?
7. What is fixed carbon?
8. What is volatile matter?
9. What is DuLong's formula?

Objectives:

1. Be able to describe the properties of coal.
2. Be able to describe what a proximate analysis shows.
3. Be able to describe what an ultimate analysis shows.

Information: In order to determine the coal best suited for a particular plant, it is necessary that you know its characteristics. This requires a proximate and an ultimate analysis.

A proximate analysis will provide information regarding moisture content, volatile matter, fixed carbon, and ash content.

An ultimate analysis will provide information for the elements found in the composition of coal.

Coal is composed of the following:

N – Nitrogen
O – Oxygen
C – Carbon
A – Ash
S – Sulphur
H – Hydrogen

Knowing the ultimate analysis and using DuLong's formula, it is possible to find the heating value of coal in B.t.u.'s per pound.

References: *Steam Plant Operation*
Combustion Engineering
Elementary Steam Power Engineering

Assignment:

1. What information can be gained from a proximate analysis?
2. What information can be gained from an ultimate analysis?
3. What are the useful elements in coal?
4. What are the effects of sulphur in the coal?
5. Is furnace volume affected when burning anthracite or bituminous coal?
6. What is the chemical composition of coal?

DuLong's Formula — Assignment 8-C-2-M1

Objective: 1. Be able to calculate the heating value of coal with DuLong's formula.

Information: A calorimeter is used to determine the actual heating value of a fuel. It is possible to calculate the heating value by using DuLong's formula. You must have the ultimate analysis of the fuel to start with.

C = % of Carbon
H = % of Hydrogen
O = % of Oxygen
S = % of Sulfur

This formula means that for every pound of carbon burned completely, 14540 B.t.u.'s will be released. For every pound of hydrogen minus 1/8 the oxygen, 62000 B.t.u.'s will be released. NOTE: The reason for this is that some of the hydrogen and oxygen unite to form water vapor. For every pound of sulfur burned completely, 4050 B.t.u.'s will be released. The sulfur content is something we can do without because of the problems it causes due to sulfuric acid attacking boiler metal.

Example: The ultimate analysis of a fuel is as follows:

Carbon	68%	Oxygen	8%
Hydrogen	5%	Sulfur	10%
Nitrogen	7%	Ash	8%

Find the heating value:

$$\begin{aligned} \text{H. V.} &= 14540C + 62000\left(H - \frac{O}{8}\right) + 4050S \\ &= 14540 \times .68 + 62000\left(.05 - \frac{.08}{8}\right) + 4050 \times .1 \\ &= 9887.20 + 2480 + 405 \\ &= 12772.2 \text{ B.t.u.'s/lb.} \end{aligned}$$

The steps used in solving the problem were:

1. $$\begin{array}{r} 14540 \\ \underline{.68} \\ 116320 \\ \underline{8724} \\ 9887.20 \end{array}$$

2. $$8\overline{)\,.08}^{\;.01} \qquad \begin{array}{r} .05 \\ -\ \underline{.01} \\ .04 \end{array} \qquad \begin{array}{r} 62000 \\ \times\ \underline{.04} \\ 2480.00 \end{array}$$

3. $$\begin{array}{r} 4050 \\ \underline{.1} \\ 405.0 \end{array}$$

4. $$\begin{array}{r} 9887.20 \\ 2480. \\ \underline{405.} \\ 12772.20 \end{array}$$

Assignment: 1. The ultimate analysis of coal is as follows:

Carbon	65%	Oxygen	11%
Hydrogen	6%	Sulfur	4%
Nitrogen	2%	Ash	12%

Find B.t.u. content.

2. The ultimate anaylsis of coal is as follows:

Carbon	85%	Oxygen	5%
Hydrogen	5%	Sulfur	1%
Nitrogen	2%	Ash	2%

Find B.t.u. content.

3. The ultimate analysis of coal is as follows:

Carbon	60%	Oxygen	16%
Hydrogen	4%	Sulfur	4%
Nitrogen	4%	Ash	12%

Find B.t.u. content.

4. The ultimate analysis of coal is as follows:

Carbon	61.5%	Oxygen	6.2%
Hydrogen	6.8%	Sulfur	5.6%
Nitrogen	3.4%	Ash	11%

Find the B.t.u. content.

5. The ultimate analysis of coal is as follows:

Carbon	80%	Oxygen	5.5%
Hydrogen	6%	Sulfur	3.5%
Nitrogen	4%	Ash	1%

Find the B.t.u. content.

Classification of Gas — Assignment 8-D-1

Objectives:

1. Be able to describe how gas is classified.
2. Be able to describe how the heat value of gas is determined.

Information: Gas is classified as either natural or manufactured. Simple, isn't it? Natural gas is a product of nature; it is found in oil fields and coal fields. Manufactured gas is produced by man.

Natural gas consists of methane, ethylene with smaller amounts of hydrogen, nitrogen, carbon monoxide, carbon dioxide, oxygen, and heavy hydrocarbons. It has gained in popularity with the new antipollution laws because it is clean and causes less pollution. Its B.t.u. content varies from 950 to 1000 B.t.u. per cubic foot.

Manufactured gas may be blast-furnace gas – coke-oven gas, illuminating gas, producer gas, or refinery gas. Its B.t.u. content varies greatly depending on how it is manufactured.

Heating value is expressed in B.t.u.'s per cubic foot. With the increase in the use of straight natural gas, modern practice rates the heating value in therms. There is approximately 100,000 B.t.u.'s per therm. The heating value is determined by a gas calorimeter or by calculations based on the chemical analysis of the gas. The heating value of each gas is determined by experiment. By analysis, the percent of each gas is determined; and this is used to determine the heating value of the gas.

References:

Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. How is gas classified?
2. How does the heating value of casing-head, blast-furnace gas, and coke-oven gas compare to each other?
3. How is the B.t.u content of natural gas rated now?
4. How is the heating value of gas found?
5. Natural gas is made up of approximately 83.5% CH_4, 14.4% C_2H_6, and 2.1% Nitrogen. What do CH_4 and C_2H_6 stand for?

Properties of Gas — Assignment 8-D-2

Objective: 1. Be able to describe the properties of natural and manufactured gas.

Information: Manufactured gas and natural gas will vary in chemical makeup. Natural gas may be dry or wet depending on where it is found. Wet natural gas is found with oil deposits, and dry natural gas is found away from oil producing wells. Dry and wet do not refer to moisture content; it refers to the gasoline content of the gas. Natural gas can also be sour or sweet. Sour gas contains high percentages of hydrogen sulfide. Sweet gas does not contain this ingredient which smells like rotten eggs. Natural gas is made up primarily of methane (CH_4) and ethane (C_2H_6). Manufactured gas will vary in the way that it is made.

Blast furnace gas, which is a waste product of furnaces used to smelt iron ore, will contain carbon dioxide, nitrogen, oxygen, carbon monoxide and hydrogen. The B.t.u. content will vary between 85 and 100 B.t.u's per cubic foot.

Coke-oven gas will have a B.t.u. content of 400 to 500 B.t.u.'s per cubic foot and will contain carbon dioxide, carbon monoxide, oxygen, methane, hydrogen and nitrogen.

References:
Steam Plant Operation
Combustion Engineering
Elementary Steam Power Engineering

Assignment:

1. Define wet gas and dry gas.
2. What is sour gas?
3. How does sour gas differ from sweet gas?
4. What is the chemical composition of natural gas?
5. What type of coal is used to produce coke-oven gas?

Safe Storage and Handling of Oil, Coal, and Gas — Assignment 8-E-1

Objective: 1. Be able to describe the safe storage and handling of oil, coal, and gas.

Information: Safety is important when handling fuel. In order to pump the heavier oils, they must be heated to lower their viscosity. If we overheat the oil in a storage tank, two things can happen:

1. As the oil becomes hotter, the sludge, sediment, and other impurities settle out in the fuel oil tank. This will build up, and eventually the tank will have to be opened and cleaned. This is an expensive job.

2. If the oil is too hot, it can reach its flash point which can lead to a fire. Boilerrooms using oil should have fire extinguishers of the proper type in strategic locations. There should also be buckets of sand available for use in case of spills or small fires. Foam or dry chemical extinguishers are used for oil fires. Never use water. Whenever an oil spill occurs, it should be cleaned up at once, and all oil rags should be disposed of immediately.

Coal offers a different problem. It is necessary to stockpile coal to meet plant needs. The coal can overheat and start to burn; this is caused by spontaneous combustion. It should be noted that anthracite is better to stockpile since it is not bothered by spontaneous combustion. Bituminous coal has a high volatile content; it must be watched carefully. In steam plant operation, there is a list of precautions to take against spontaneous combustion.

Gas is very explosive and toxic. All gas lines should be tested for leaks by using a liquid soap solution. Vent lines from regulators, reducing valves, or governors should be piped out of the boilerroom to an area where they can be discharged safely. Any odor of gas must be checked out at once. If gas is allowed to build up and to get to the point where there is a proper mixture of gas and air, and if it comes in contact with an open spark or flame, the resulting explosion can be deadly.

References *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. What are the results of too high a temperature of oil in the storage tank?
2. How would you take care of an oil spill?
3. a. What is the purpose of an oil vent on an oil tank?
   b. What precautions should be taken in regard to this vent line?
4. What type of fire extinguisher should be on hand in plants burning oil?
5. Would you use water to put out an oil fire? Explain.
6. What is spontaneous combustion?
7. List the precautions to follow to prevent spontaneous combustion.
8. Why is soft coal more prone to spontaneous combustion than hard coal?
9. How would you recommend checking gas lines for leaks?
10. Why should all vent lines from gas-control valves be vented outside the boilerroom?

Oil Tanks and Piping — Assignment 9-A-1

Objectives:

1. Be able to locate the fuel oil tanks in the school plant.
2. Be able to explain the reasons for knowing the location of all fuel oil piping in a plant.

Information: In order for a fireman to operate a plant safely and efficiently, he must know his plant well. Know the location of all fuel oil lines, valves, pumps, regulators, and crossover connections. Know how to swing over from one fuel oil tank to another. Know how to change over pumps and heaters. Know the temperatures and pressures in your system because they are an indication of either a normal operating plant, or a plant about to get into serious trouble. No two plants are alike. They may have the same basic equipment, but their location will vary. The fireman must trace out all the lines, make a rough sketch of all valves, regulators, strainers, heater, pumps etc., and then go over in his own mind how he would handle each emergency, before it happens. When things start to go wrong in a plant there is not time to think; there is only time to take decisive action to save the plant. A fireman is responsible for maintaining steam pressure on his boiler for production.. If the boiler goes down, all production goes down. If the plant is generating the turbine goes down, and the complete plant is dead. This must not happen and will not happen if the operator is on his toes. Knows your plant and operate it intelligently. Good operators are not born; they are made!

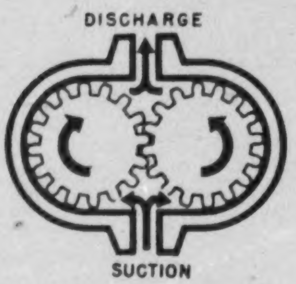
Assignment:

1. a. What is the capacity of the school fuel oil tank?
   b. What temperature do we maintain in our fuel oil tank?
   c. What would happen if the temperature dropped too low?
   d. What might happen if the temperature got too high?
2. How is heat supplied to the fuel oil tank?
3. What is the purpose of the vent on the fuel oil tank?
4. What would happen if the vent were clogged when taking oil?
5. What would happen if the vent were clogged when firing the boiler?
6. How can air enter the fuel oil system?
7. How can we rid the system of air once it is in the system?
8. Explain how the temperature in the fuel oil tank is controlled?

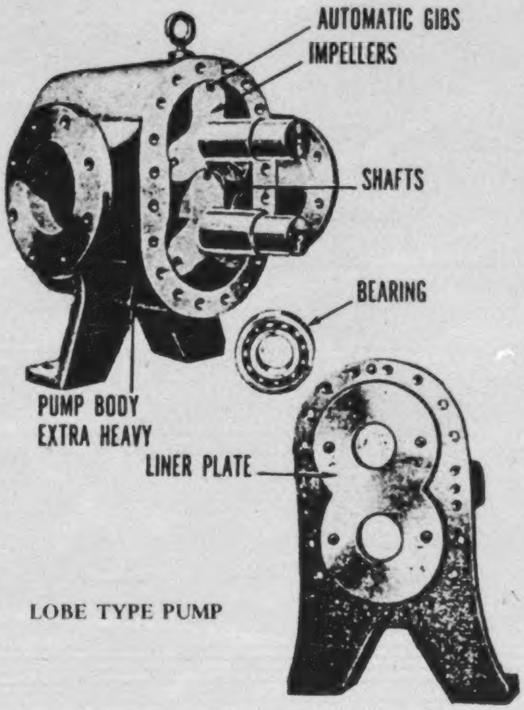
Objectives:

1. Be able to explain the purpose of fuel and pumps.
2. Be able to describe the basic types of fuel oil pumps.
3. Be able to explain the need for fuel oil heaters.

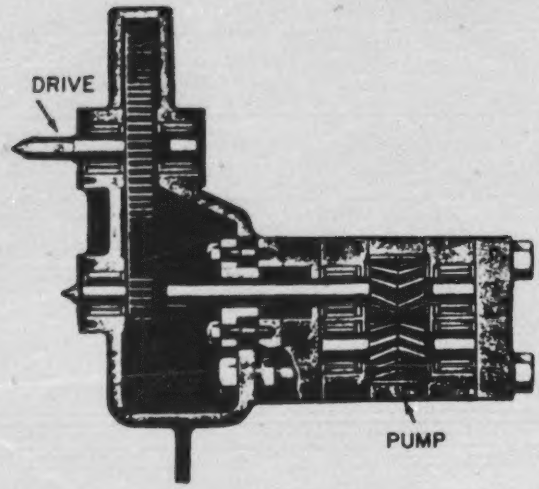
Information: Storage of fuel oil is in tanks that are either above or below ground. Fuel oil pumps deliver the oil to the burner under pressure. The pumps are positive displacement pumps which means there is always a positive discharge of oil. They can be reciprocating, gear, screw, or lobe type pumps. The pumps will be protected with a relief valve and some type of pressure regulator to control the pressure of the oil at the burner. Not all oil is deliverd to the burner. Some of the oil will be returned to the tank. This keeps the oil in the lines warm at all times.


DISCHARGE
SUCTION

SIMPLE GEAR PUMP


AUTOMATIC GIBS
IMPELLERS
SHAFTS
BEARING
PUMP BODY
EXTRA HEAVY
LINER PLATE

LOBE TYPE PUMP

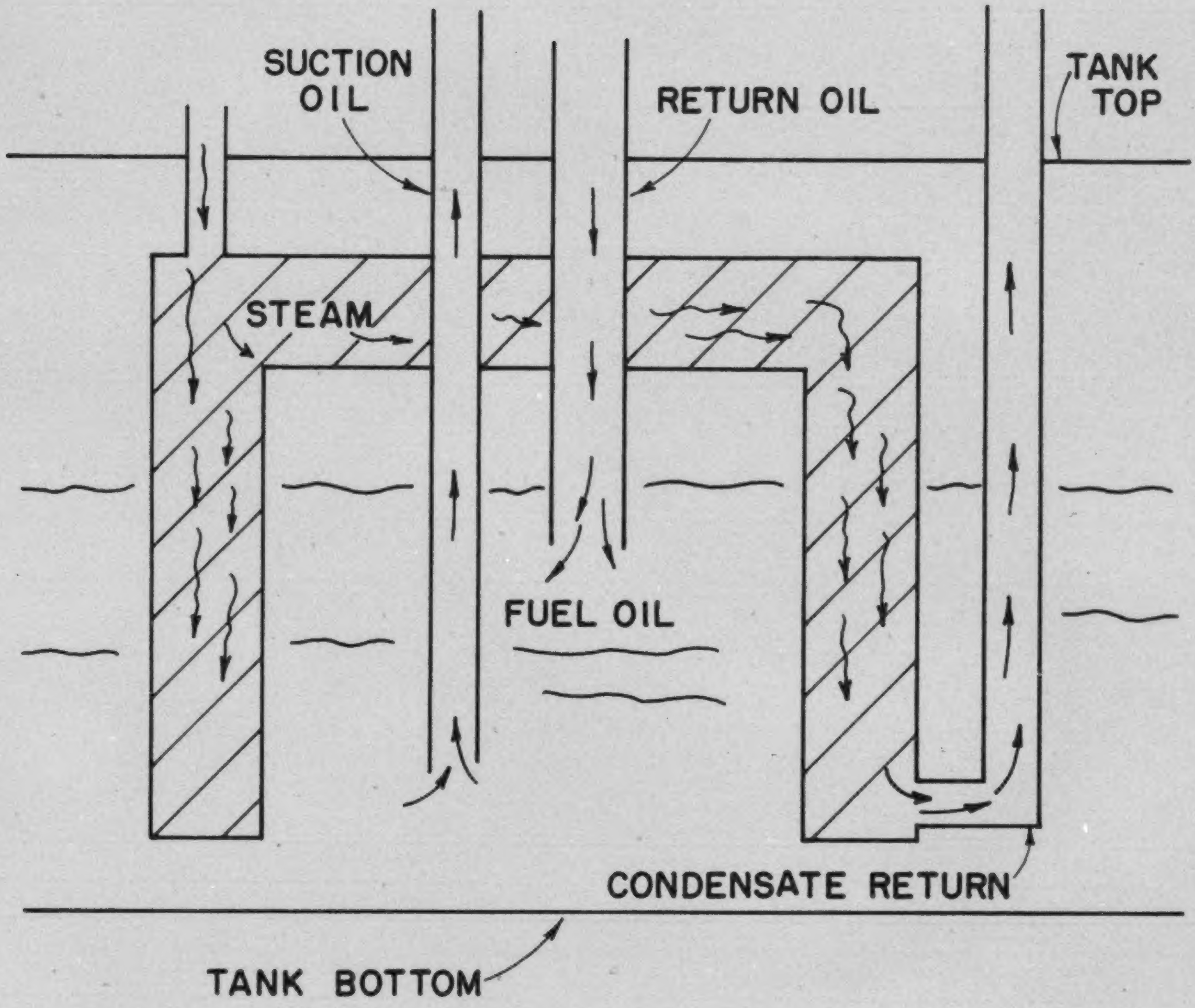


HERRINGBONE GEAR PUMP

The oil in the tank is kept warm by using either heating coils, a heating bell, or electric pipeline heaters. The heating bell or coils have either steam or hot water circulating through them to maintain the proper temperature. The oil in the tank must never be heated above its flash point in the tank. After the oil leaves the tank, there is usually a steam or water heater near the fuel oil pumps and an electric heater at the burner to bring the oil up to its firing point. The returns from steam heated coils or heaters must be carefully monitored to prevent any fuel oil from entering the return lines and getting back into the boiler. Oil in the steam and water side of the boiler causes foaming which can lead to burning out of the boiler tubes.

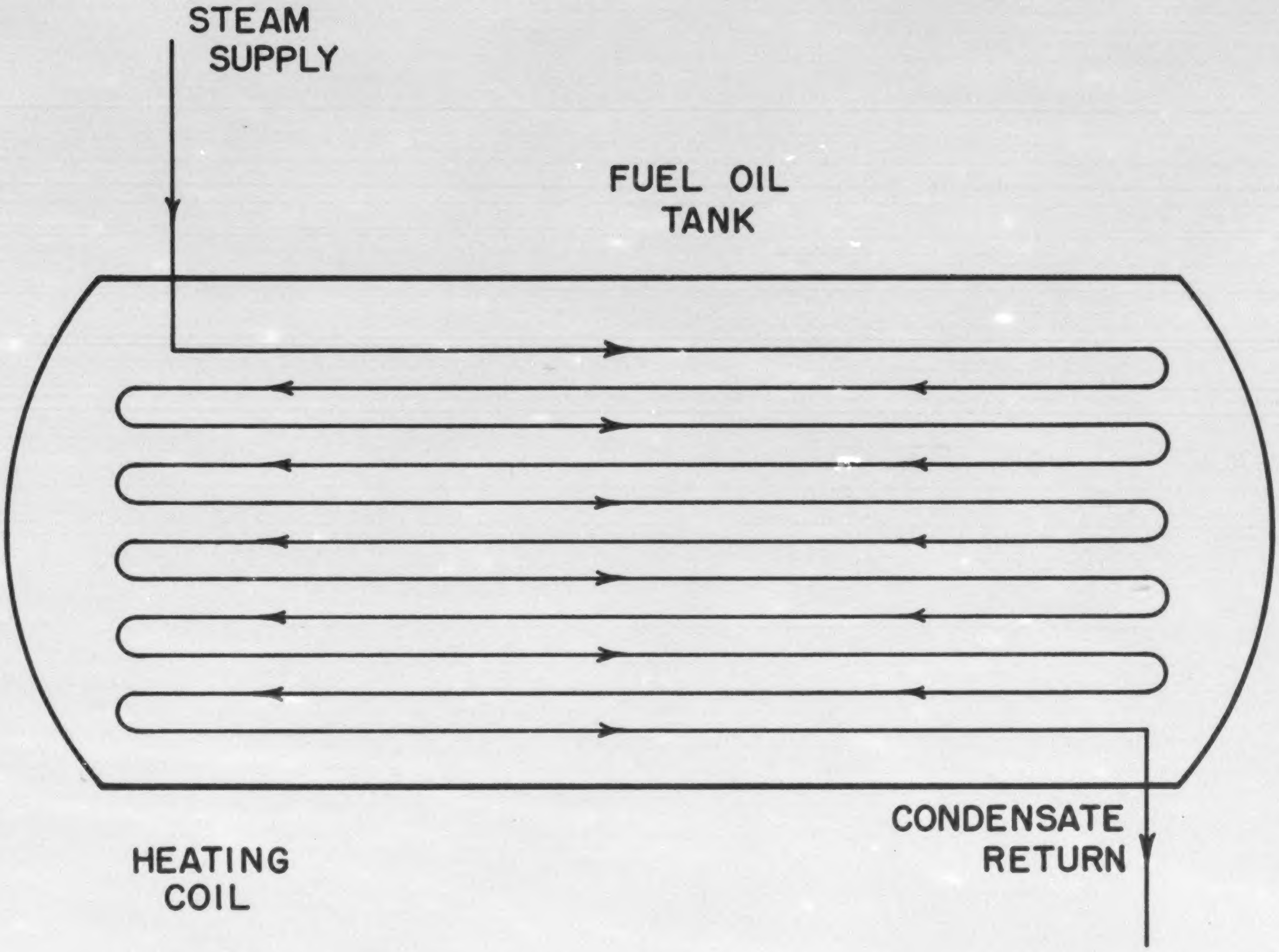
Assignment:

1. What is the purpose of a fuel oil pump?
2. Why are gear pumps often used for fuel oil pumps?
3. Why are fuel oil pumps equipped with relief valves? Where are these relief valves located?
4. What would happen if you had a leak on the suction side of the fuel oil pump?
5. How is the oil in our fuel oil tanks heated?
6. Why is it necessary to heat the oil in our tanks?
7. How does heating the oil affect its viscosity?
8. How is the temperature of the oil controlled on the following:
    a. Fuel oil tank #1
    b. Fuel oil tank #2
    c. Steam heaters
    d. Electric heaters


SUCTION OIL
RETURN OIL
TANK TOP
STEAM
FUEL OIL
CONDENSATE RETURN
TANK BOTTOM

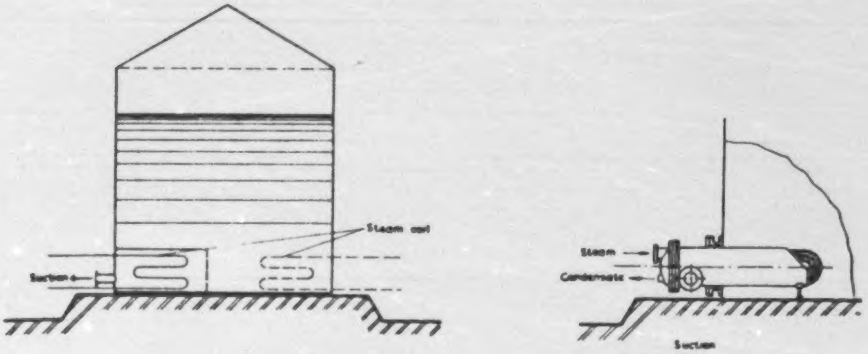
HEATING BELL

9-A-2-2


STEAM SUPPLY
FUEL OIL TANK
HEATING COIL
CONDENSATE RETURN

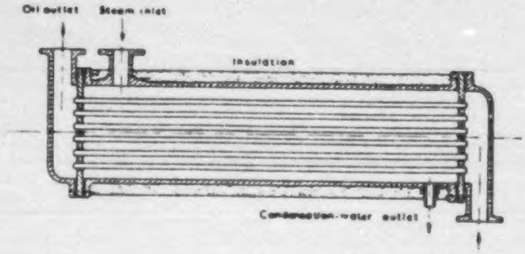
9-A-2-3

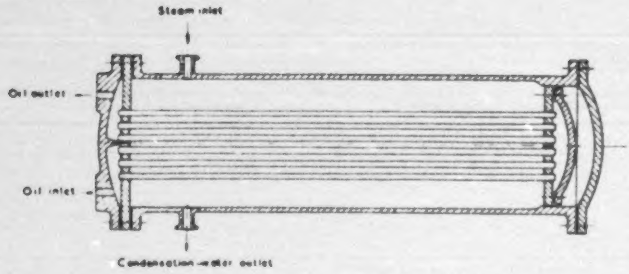
TYPICAL STORAGE TANK SUCTION HEATERS

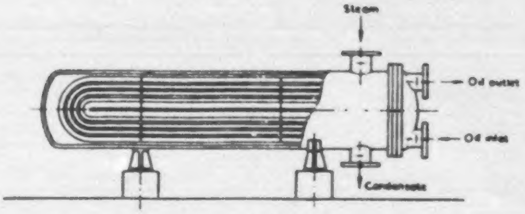

Steam coil
Suction
Steam
Condensate
Suction

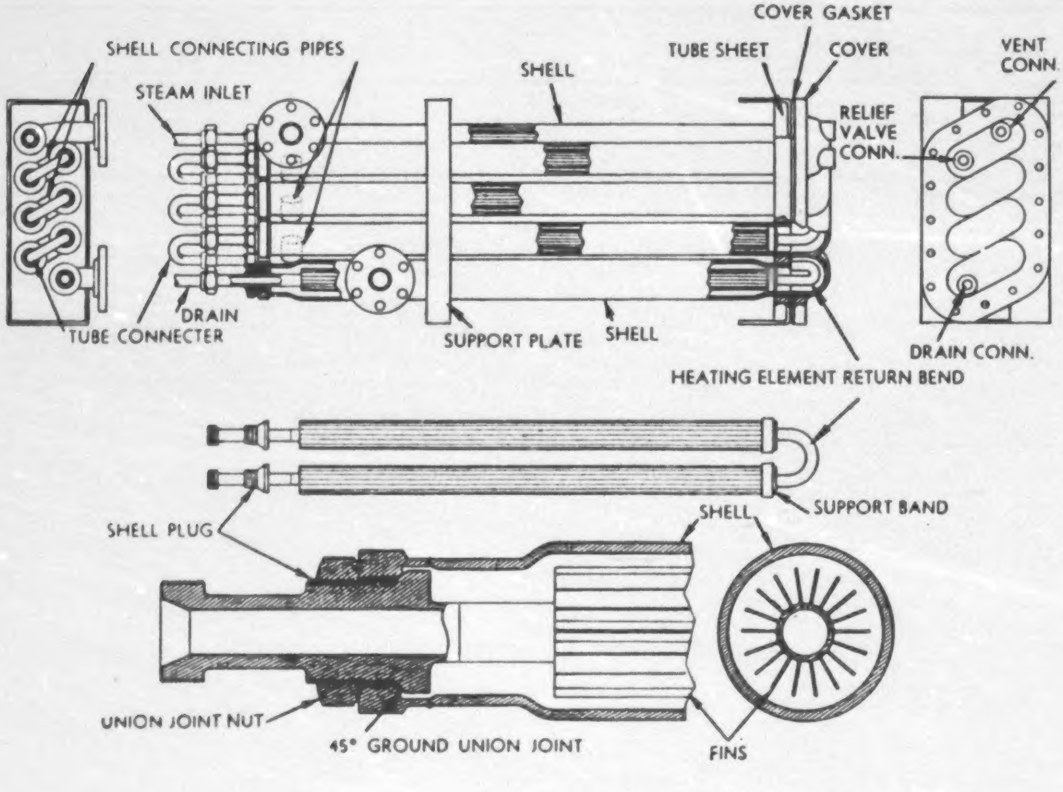
9-A-2-4

TYPICAL TUBULAR FUEL OIL HEATERS


Oil outlet
Steam inlet
Insulation
Condensation-water outlet


Steam inlet
Oil outlet
Oil inlet
Condensation-water outlet


Steam
Oil outlet
Oil inlet
Condensate


COVER GASKET
SHELL CONNECTING PIPES
TUBE SHEET
COVER
VENT CONN.
SHELL
STEAM INLET
RELIEF VALVE CONN.
DRAIN
TUBE CONNECTER
SUPPORT PLATE
SHELL
DRAIN CONN.
HEATING ELEMENT RETURN BEND
SHELL
SUPPORT BAND
SHELL PLUG
UNION JOINT NUT
45° GROUND UNION JOINT
FINS

9-A-2-5

Gear Pumps — Assignment 9-A-3

Objectives:

1. Be able to identify the parts of a gear pump.
2. Be able to list the advantages and disadvantages of gear pumps.

Information: The gear pump is a type of rotary pump. Although its motion is the same as a centrifugal pump, its theory of operation is entirely different. It does, however, provide a constant discharge pressure like a centrifugal pump, but it is a positive displacement pump.

The advantages of the gear pump are:

1. Few moving parts
2. Low initial cost
3. Small in size
4. Constant pressure
5. Self priming
6. High suction lift
7. Can handle high-viscosity liquids.

Its disadvantages are:

1. Slow speed
2. Noisy
3. Efficiency drops quickly when teeth wear
4. Low-viscosity liquids hard to handle at high pressure due to increased slippage

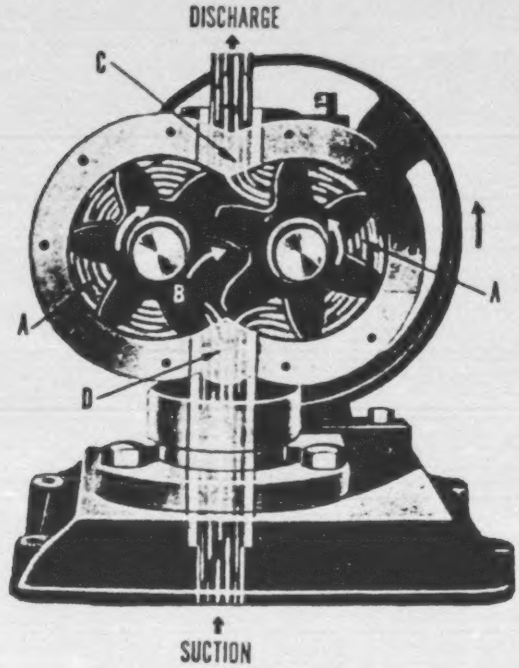
The operating characteristics of a gear pump makes it ideal for use as a fuel oil pump. As in any other type of equipment there are different designs. The sketches on the following pages will help you to identify them.

References:

Steam Plant Operation
Manufacturers Data Sheets

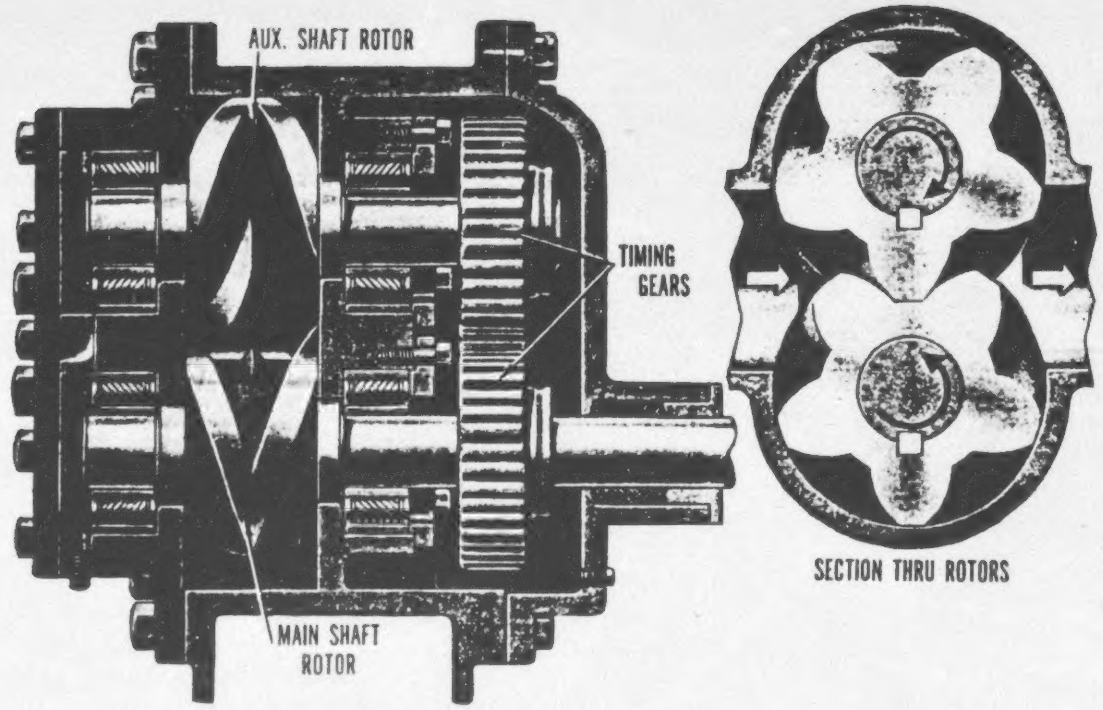
Assignment:

1. Why is a gear pump suitable as a fuel oil pump?
2. How does a gear pump compare to a centrifugal pump?
3. How does a gear pump compare to a reciprocating pump?
4. From what you have observed, do you think a gear pump needs a relief valve? If it does, where would it be located?
5. Discuss the advantages and disadvantages of a gear pump.


DISCHARGE
C
A
B
A
D
SUCTION

A – Liquid
B – Gears
C – Discharge Port
D – Suction Ports

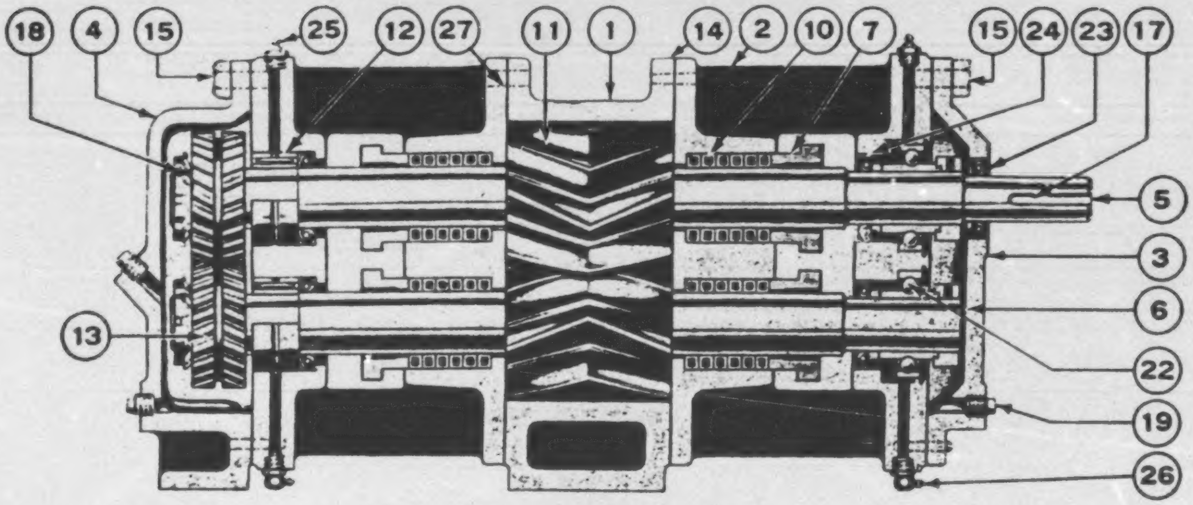
END VIEW SIMPLE GEAR PUMP


AUX. SHAFT ROTOR
TIMING GEARS
MAIN SHAFT ROTOR
SECTION THRU ROTORS

HELICAL TYPE GEAR PUMP

9-A-3-1

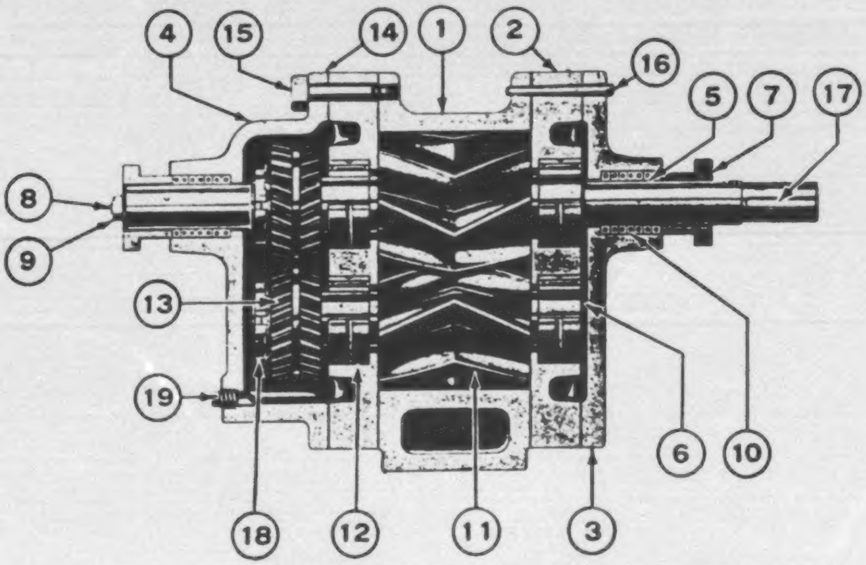
EXTERNAL BEARING TYPE



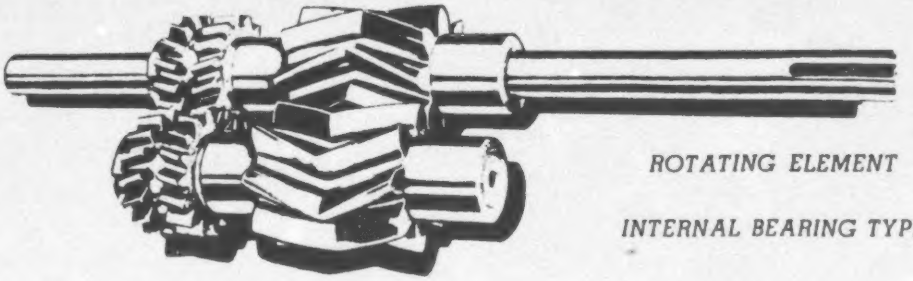
1. BODY
2. BEARING BRACKET
3. FRONT HEAD
4. REAR HEAD
5. DRIVE SHAFT
6. DRIVEN SHAFT
7. GLAND
8. GLAND STUD*
9. GLAND NUTS*
10. GLAND PACKING
11. ROTORS
12. ROLLER BUSHINGS
13. TIMING GEARS
14. HEAD GASKETS
15. HEAD BOLTS
16. HEAD DOWELS*
17. COUPLING KEY
18. LOCKNUT AND WASHER
19. DRAIN PLUG
20. GEAR KEYS*
21. ROTOR KEYS*
22. FRONT BEARINGS
23. FRONT HEAD SEAL
24. BRACKET SEAL
25. ZERK FITTING—T
26. ZERK FITTING—R
27. BODY BOLTS
28. ROTOR SPACERS*
29. BEARING SNAP RING*

9-A-3-2

INTERNAL BEARING TYPE



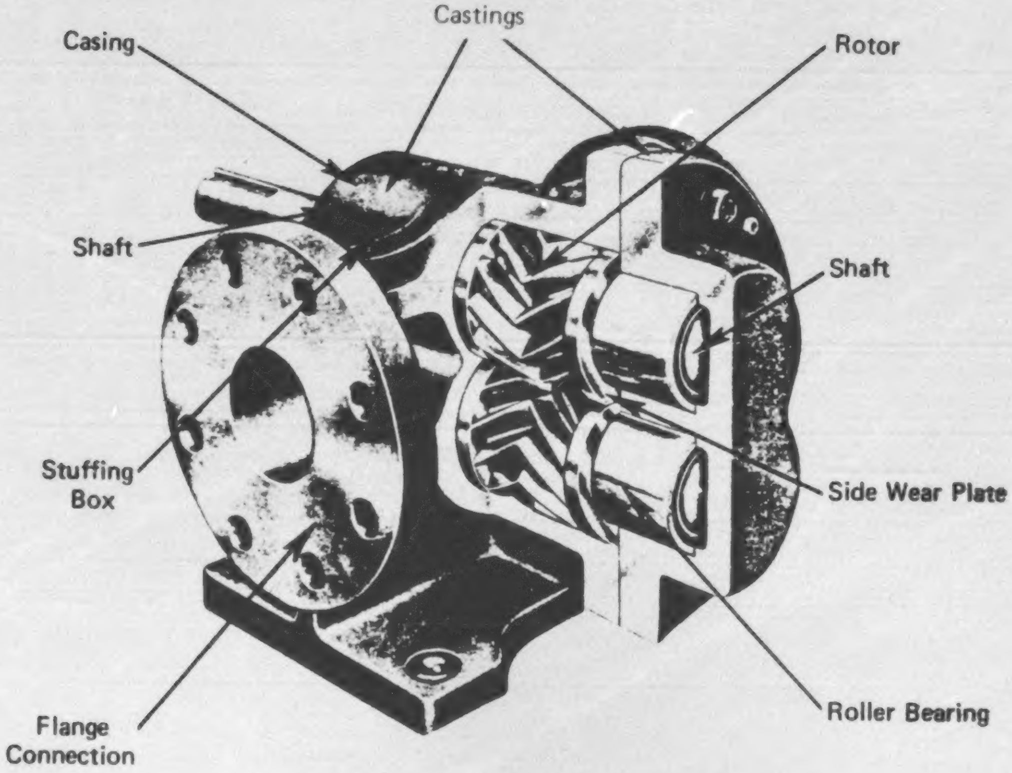
1. BODY	8. GLAND STUD	15. HEAD BOLTS
2. BEARING SPACER	9. GLAND STUD NUT	16. HEAD DOWELS
3. FRONT HEAD	10. GLAND PACKING	17. COUPLING KEY
4. REAR HEAD	11. ROTORS	18. LOCKNUT AND WASHER
5. DRIVE SHAFT	12. ROLLER BUSHINGS	19. DRAIN PLUG
6. DRIVEN SHAFT	13. TIMING GEARS	20. TIMING GEAR KEYS
7. GLAND	14. HEAD GASKETS	21. ROTOR KEYS

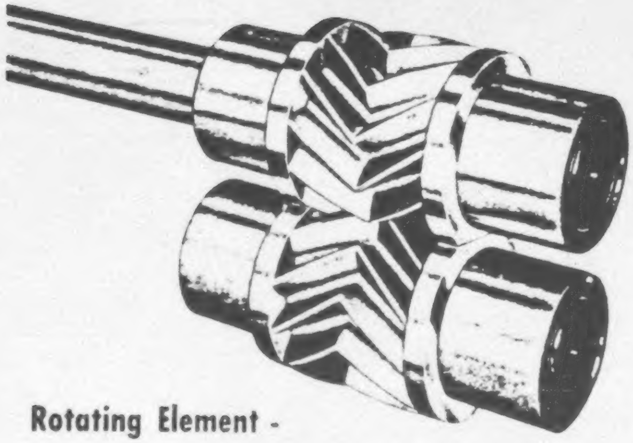


ROTATING ELEMENT

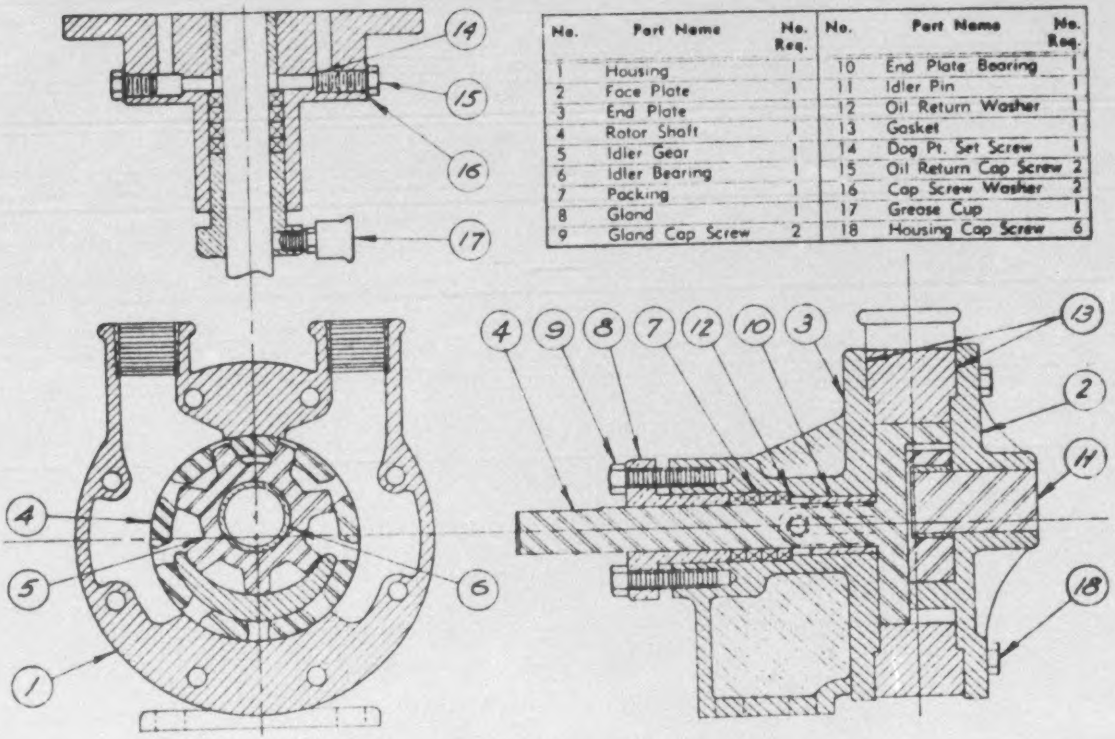
INTERNAL BEARING TYPE

9-A-3-3


Castings
Casing
Rotor
Shaft
Shaft
Stuffing Box
Side Wear Plate
Roller Bearing
Flange Connection



Rotating Element -



No.	Part Name	No. Req.	No.	Part Name	No. Req.
1	Housing	1	10	End Plate Bearing	1
2	Face Plate	1	11	Idler Pin	1
3	End Plate	1	12	Oil Return Washer	1
4	Rotor Shaft	1	13	Gasket	1
5	Idler Gear	1	14	Dog Pt. Set Screw	1
6	Idler Bearing	1	15	Oil Return Cap Screw	2
7	Packing	1	16	Cap Screw Washer	2
8	Gland	1	17	Grease Cup	1
9	Gland Cap Screw	2	18	Housing Cap Screw	6

9-A-3-5

Pressure Atomizing Burner — Assignment 9-A-4

Objectives:

1. Be able to describe how a pressure atomizing burner works.
2. Be able to describe how the amount of oil burned is controlled.

Information: The quantity of oil delivered by the atomizer is controlled by:

1. Oil pressure
2. Tip orifice diameter
3. Plug channel dimensions

The burner's job is to deliver fuel oil in a fine spray and to mix a sufficient amount of air with the oil for efficient combustion. In order to do this, the burner has

1. An atomizer which delivers oil to fire box in fine mist.
2. An air register which admits air to fire box.
3. Valves and fittings which connect the atomizer to the oil lines.

The two types of atomizers shown in Figure 9-A-4-1 are the plug and tip types. Figure 9-A-4-2 shows the sprayer plate type.

The air register performs these three functions:

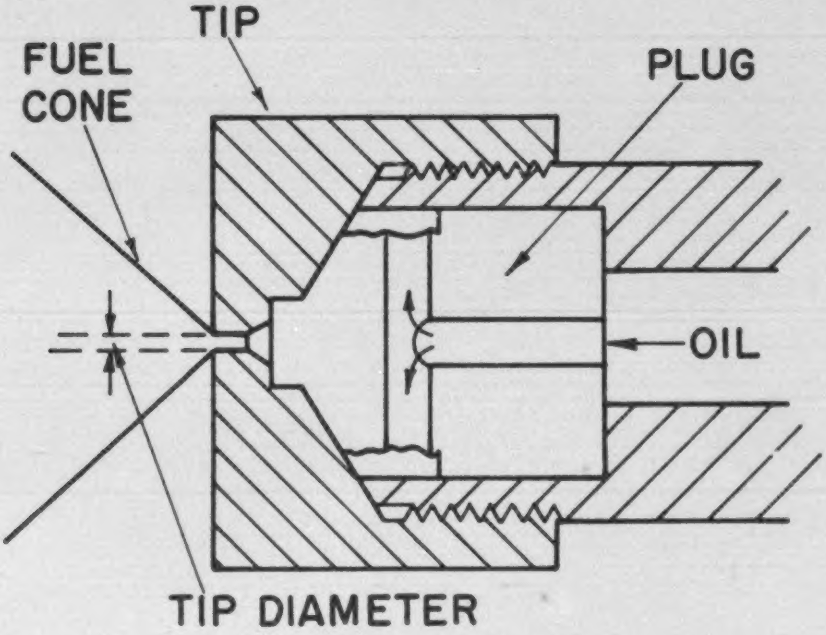
1. Gives air a whirling motion, which helps bring each particle of oil into close contact with air thus aiding in combustion.
2. Controls amount of air that enters fire box. No air goes in when flaps are closed.
3. Controls the velocity of air entering the fire box.

References:

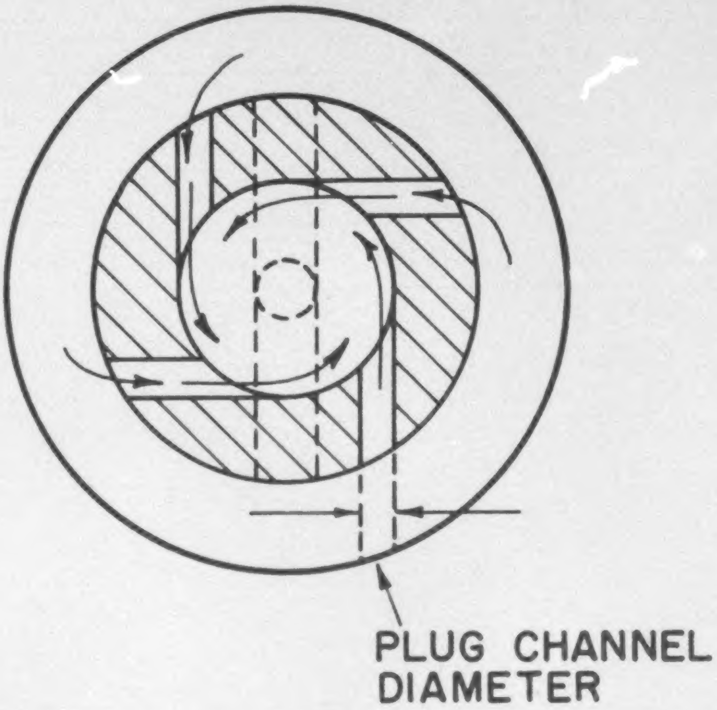
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

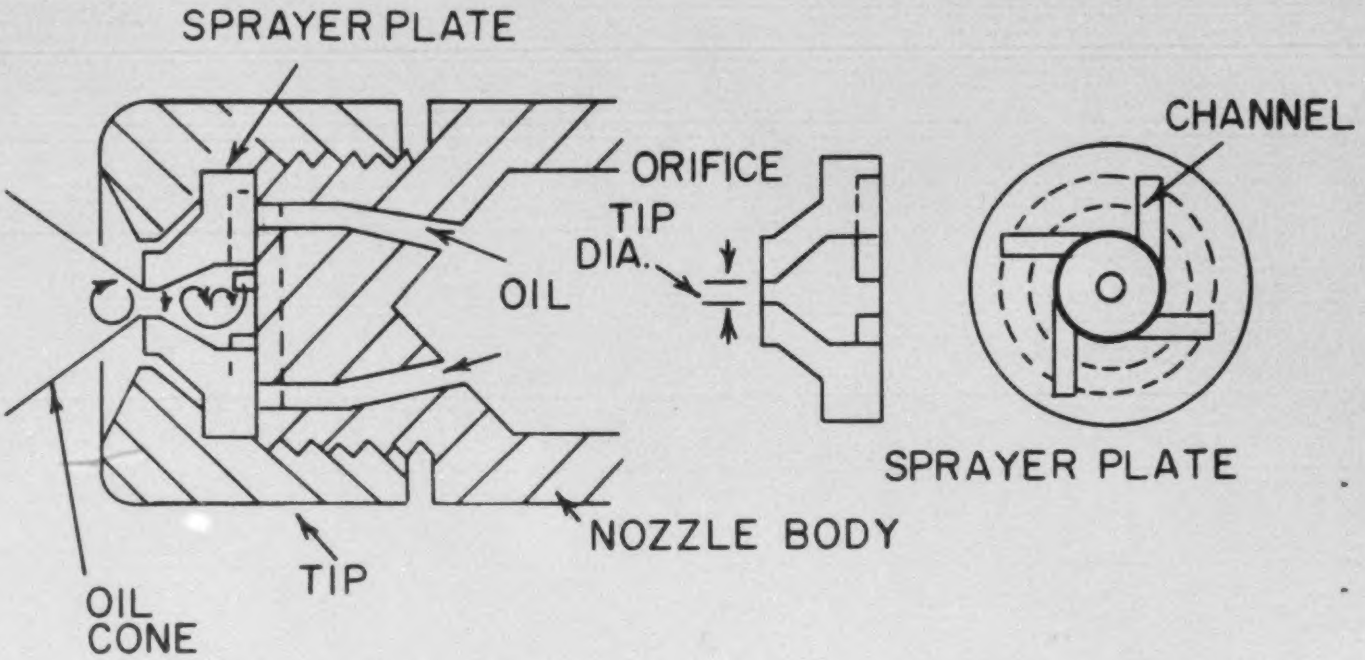
1. How can the amount of oil delivered be controlled?
2. What determines the amount of oil entering the return line?
3. At what pressure is the oil supplied to a mechanical atomizing burner?
4. What is the range or capacity of a mechanical atomizing burner?
5. Approximately how much boiler horsepower can a mechanical atomizing burner develop?
6. What type of spray is produced by a mechanical atomizing burner?


TIP
FUEL CONE
PLUG
OIL
TIP DIAMETER

PLUG AND TIP TYPES


PLUG CHANNEL DIAMETER

9-A-4-1


SPRAYER PLATE
ORIFICE
TIP
DIA.
OIL
CHANNEL
SPRAYER PLATE
NOZZLE BODY
TIP
OIL
CONE

SPRAYER-PLATE ATOMIZER

9-A-4-2

Rotary Cup Burner — Assignment 9-A-5

Objectives:

1. Be able to explain why rotary cup burners are used.
2. Be able to describe how oil pattern can be regulated.

Information: The rotary cup burner, which was once used only in low-pressure plants, has gained in popularity with the introduction of high-pressure package type boilers. It can burn a wide range of fuel at relatively low temperatures and pressures. It is ideal for complete automatic operation. A combination gas or oil fired boiler makes a plant that is very flexible. To change from oil to gas often means just opening a manual shutoff valve on the gas line and throwing the selector switch to gas.

The rotary cup burner has also been used on ocean-going ships. Figure 9-A-5-1 shows a direct drive model and Figure 9-A-5-2 shows a belt drive model. The schematic, Figure 9-A-5-3, shows how the flame patterns can be changed by using different angular vane nozzles. This is very important since it will prevent oil impingement and will lead to more complete combustion.

The pressure of the oil does not affect the atomization of the oil. This is accomplished by the spinning cup and the angular vane air nozzle. The oil is delivered through a fuel tube which passes through a hollow shaft. As the oil in a thin film spins off the end of the oil cup, it enters the high-speed cone of air which helps to break it up. These angular vanes of the air nozzle are installed so that the air will rotate in the opposite direction of the atomizing cup. The primary air which is being supplied by the burner fan provides only about 15% of the air that is required for combustion. It is necessary to supply secondary air for the complete combustion of fuel.

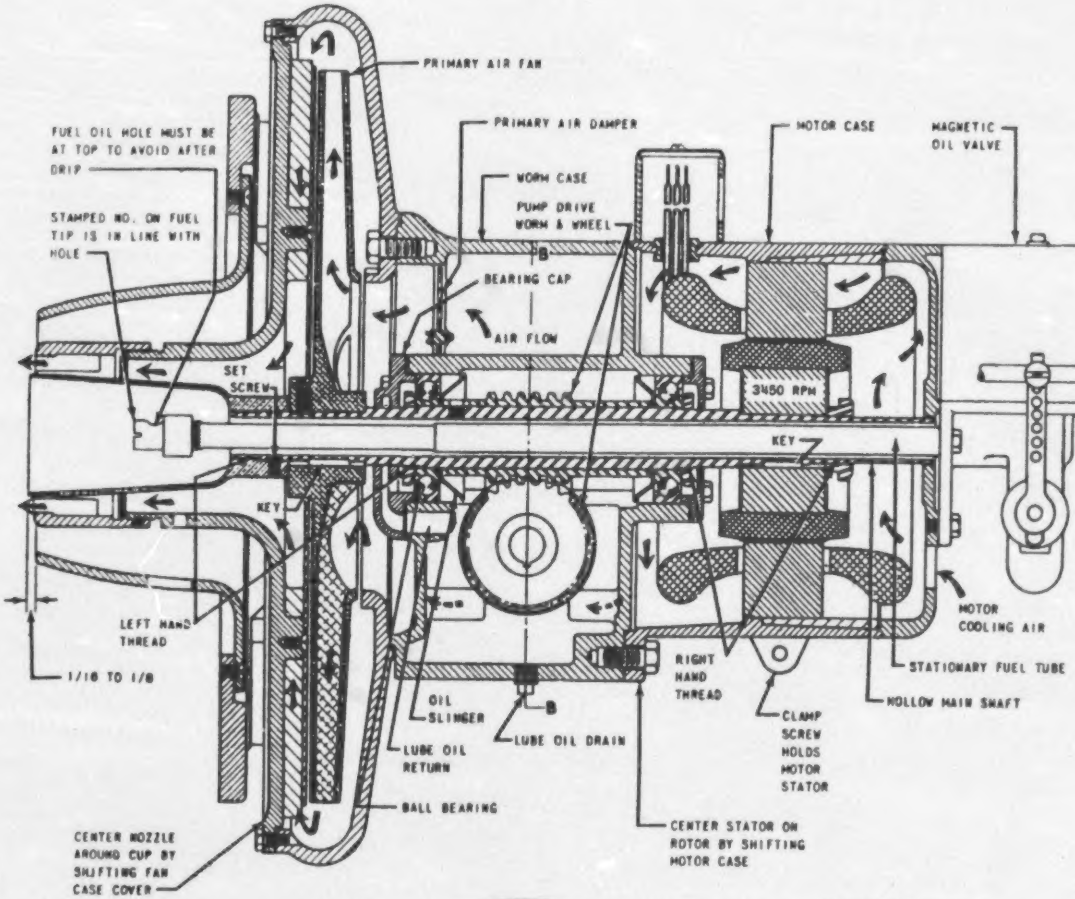
A sail switch or air switch is located at the burner fan housing to prove primary air pressure. It is usually wired into the system, so that the burner motor will run and purge; but the progamming clock is cut out of the cycle. The dial will continue to move; but there is no ignition, and the oil valve can not open.

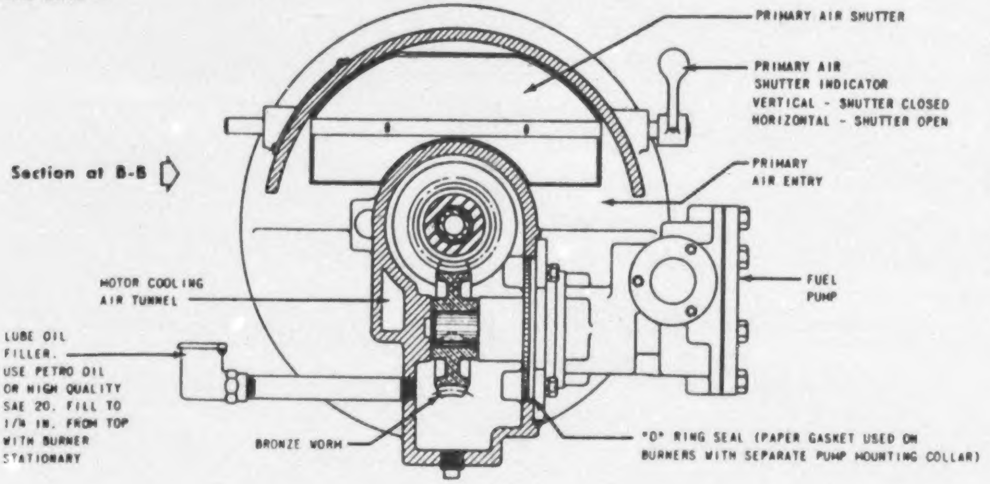
References:

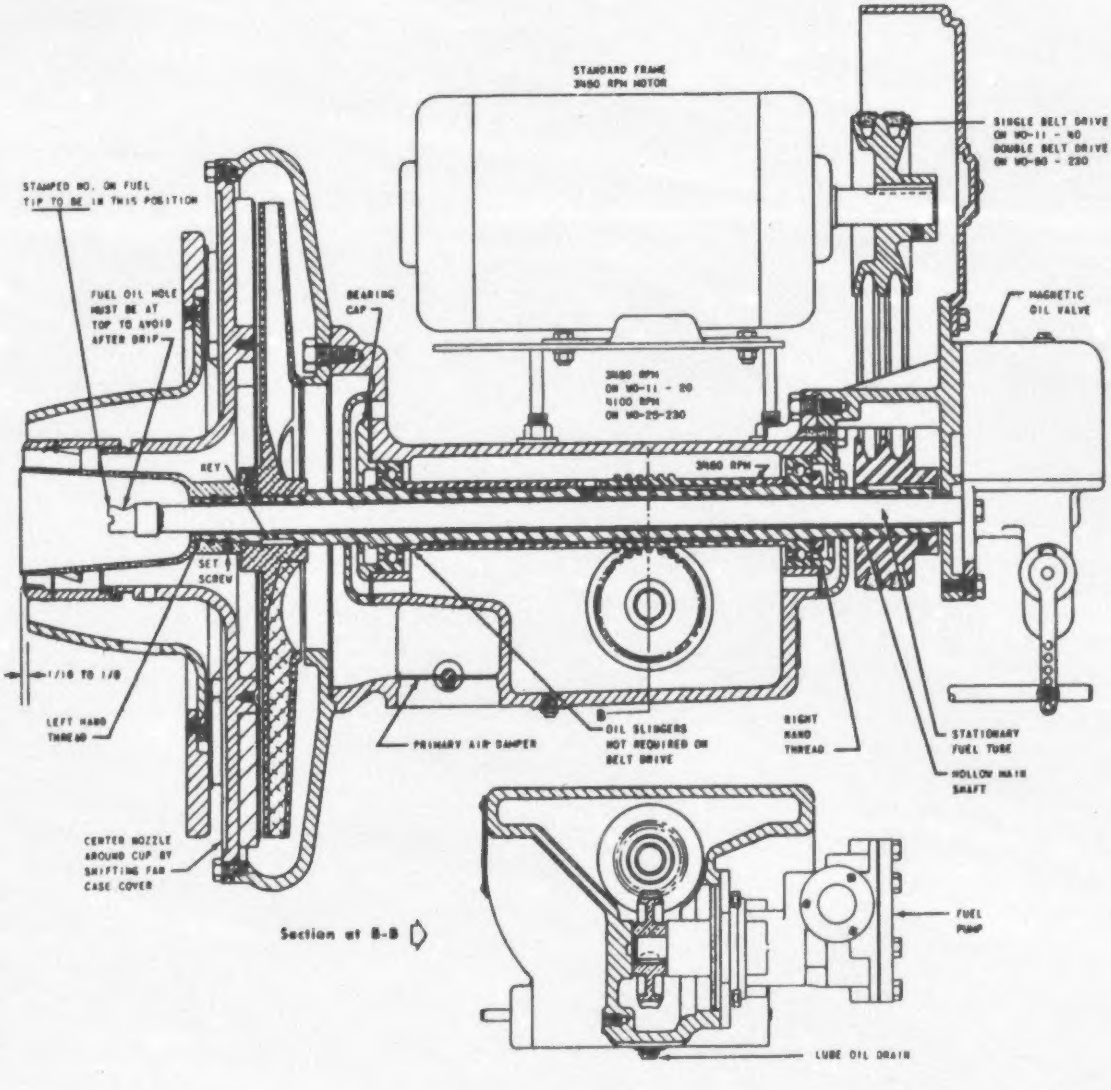
Steam Plant Operation
Petro Manual – Installation and Service

Assignment:

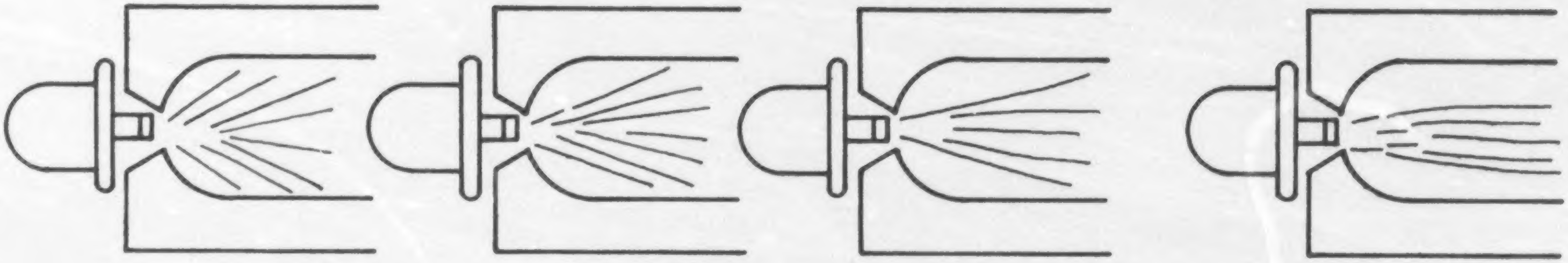
1. How is the oil pattern controlled in a rotary cup burner?
2. Does the primary air play any part in atomizing the oil? Explain.
3. How is the primary air supplied to the burner?
4. Why is secondary air required?
5. How is the burner protected against primary air failure?
6. Does a rotary cup require high or low oil pressure for atomization of oil?


PRIMARY AIR FAN
FUEL OIL HOLE MUST BE AT TOP TO AVOID AFTER DRIP
PRIMARY AIR DAMPER
MOTOR CASE
MAGNETIC OIL VALVE
WORM CASE
PUMP DRIVE WORM & WHEEL
STAMPED NO. ON FUEL TIP IS IN LINE WITH HOLE
B
BEARING CAP
AIR FLOW
SET SCREW
3450 RPM
KEY
KEY
LEFT HAND THREAD
1/16 TO 1/8
MOTOR COOLING AIR
RIGHT HAND THREAD
STATIONARY FUEL TUBE
HOLLOW MAIN SHAFT
OIL SLINGER
B
LUBE OIL DRAIN
CLAMP SCREW HOLDS MOTOR STATOR
LUBE OIL RETURN
BALL BEARING
CENTER STATOR ON ROTOR BY SHIFTING MOTOR CASE
CENTER NOZZLE AROUND CUP BY SHIFTING FAN CASE COVER


PRIMARY AIR SHUTTER
PRIMARY AIR SHUTTER INDICATOR VERTICAL - SHUTTER CLOSED HORIZONTAL - SHUTTER OPEN
Section at B-B
PRIMARY AIR ENTRY
MOTOR COOLING AIR TUNNEL
FUEL PUMP
LUBE OIL FILLER. USE PETRO OIL OR HIGH QUALITY SAE 20. FILL TO 1/4 IN. FROM TOP WITH BURNER STATIONARY
BRONZE WORM
"O" RING SEAL (PAPER GASKET USED ON BURNERS WITH SEPARATE PUMP MOUNTING COLLAR)


STANDARD FRAME
3450 RPM MOTOR
SINGLE BELT DRIVE ON WO-11 - 40
DOUBLE BELT DRIVE ON WO-60 - 230
STAMPED NO. ON FUEL TIP TO BE IN THIS POSITION
FUEL OIL HOLE MUST BE AT TOP TO AVOID AFTER DRIP
BEARING CAP
MAGNETIC OIL VALVE
3450 RPM ON WO-11 - 20
4100 RPM ON WO-25-230
KEY
3450 RPM
SET SCREW
1/16 TO 1/8
LEFT HAND THREAD
PRIMARY AIR DAMPER
B
OIL SLINGERS NOT REQUIRED ON BELT DRIVE
RIGHT HAND THREAD
STATIONARY FUEL TUBE
HOLLOW MAIN SHAFT
CENTER NOZZLE AROUND CUP BY SHIFTING FAN CASE COVER
Section at B-B
FUEL PUMP
LUBE OIL DRAIN

9-A-5-2



55° 65° 75° 90°

FLAME PATTERN

9-A-5-3

Objectives:

1. Be able to describe the types of steam atomizing burners.
2. Be able to describe how steam atomizing burners work.

Information: There are two basic types of steam atomizing burners. On one the oil and steam meet outside the burner; it is called an outside-mixing type and is shown in Figure 9-A-6-1. In the other type, the oil and steam mix inside the burner; it is called an inside-mixing type and is shown in Figure 9-A-6-2. The steam serves one purpose; it atomizes the oil.

The steam atomizing burner is used in smaller boilers. It can burn a poorer grade of fuel with a shorter fire. It costs less than the mechanical atomizing burner initially, but it does cost more to operate because of the need for live steam to atomize the oil. It is easy to change the flame pattern to accommodate the fire box, and excellent mixing of fuel and air can be achieved.

The inside-mixing type of burner is the most common burner used. No. 6 oil must still be heated, but it is heated to a much lower degree (approximately 120° to 150°F). The oil is supplied at a pressure of about 50 p.s.i., and the steam pressure is about 20 pounds higher. Live steam is used to atomize the oil, and the steam consumption will vary with operating conditions. Under ideal conditions, 1% of the total steam generated is claimed to be used for atomization. A more realistic figure of 2% to 3% would be more likely. If it were much higher, it would be a sign of poor operation.

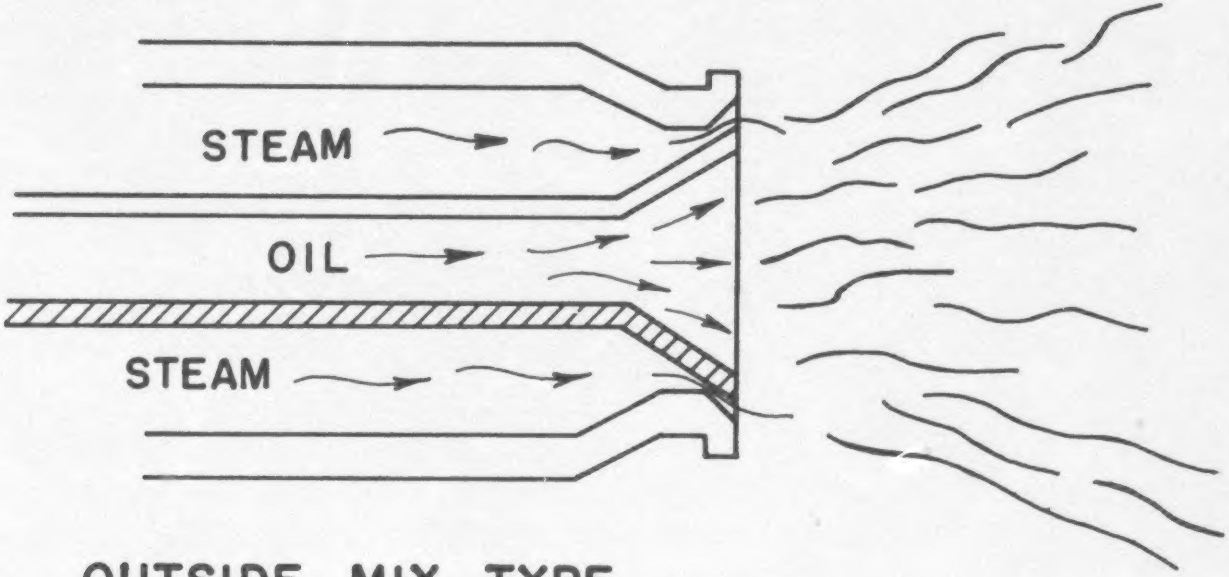
In plants using steam atomizing burners, pressure regulators are used on both the oil and steam lines to the burner. The pressure differential between the oil and steam is about 20 pounds – the steam being higher. This spread will be maintained automatically over a fair range as the load increases or decreases.

References:

Steam Plant Operation
Elementary Steam Power Engineering

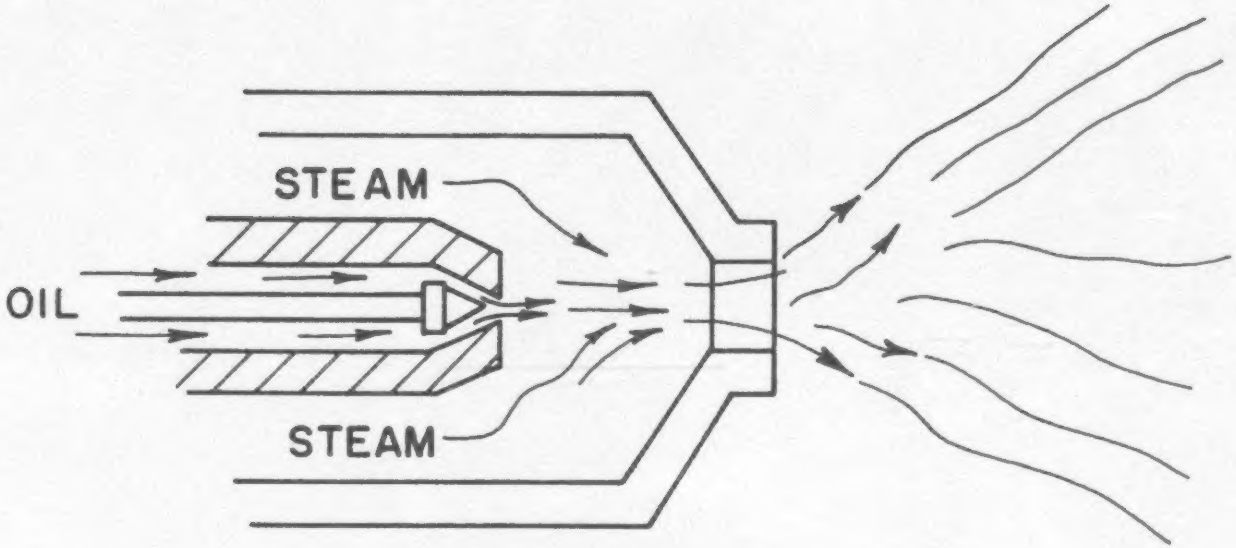
Assignment:

1. Describe the operation of an inside-mix and outside mix burner.
2. What purpose does the steam serve?
3. How much steam is consumed using a steam atomizing burner?
4. What are the advantages of using steam atomizing burners?


STEAM
OIL
STEAM

OUTSIDE MIX TYPE

9-A-6-1


STEAM
OIL
STEAM

INSIDE MIX TYPE

9-A-6-2

Objectives:

1. Be able to explain why stokers were developed.
2. Be able to describe the types of stokers.

Information: Stokers were developed because of the inefficiency of hand firing and the limits of the size of boilers being hand fired. As the demands for steam increased, larger boilers were necessary. Some form of mechanical feeding coal had to be devised.

Coal was the principle fuel used in boilers when James Watt was issued a patent in 1785. The patent described a device that combined a hopper, grate to burn the fuel, and way of ash removal. However, it was much later before stokers were developed. The book, *Combustion Engineering,* has an interesting section on the historical development of the stoker.

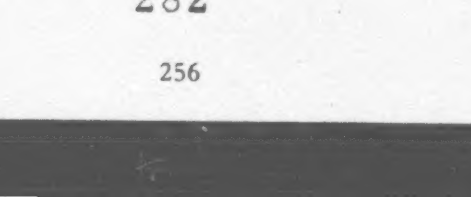
Stokers are classified as to coal feed; there are three general types:

1. Overfeed
2. Underfeed
3. Crossfeed

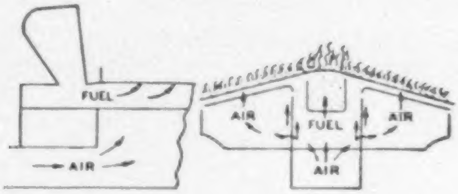
The stoker must be designed to allow or accomplish the following:

1. Feed coal continually or intermittently.
2. Provide some means of igniting the coal.
3. Provide adequate air for combustion of fuel and a means of distributing the gases of combustion over the heating surface and out to the stack.
4. Provide for ash removal.

The chain grate or traveling grate stoker in Figure 9-B-1-1 is an example of a crossfeed stoker. It is capable of burning a high volatile, high ash, noncaking coal. It is built with a grate surface area of 25 to 600 square feet. Its burning rate will vary from 20 to 35 pounds of anthracite per square foot per hour and 30 to 50 pounds of bituminous per square foot per hour when using forced draft.

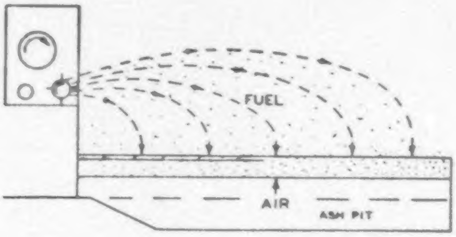


The underfeed stoker shown in Figure 9-B-1-2 has coal fed in from the bottom as the name implies. It can be screw fed or ram fed, and it can be single retort or multiretort. It is used in small, medium, and large boilers by using single retort, double retort or multiretort stokers.



9-B-1-2

The overfeed stoker shown in Figure 9-B-1-3 is known as a spreader or sprinkler stoker. The coal is introduced to the firebox above the grates; some of the coal is burned in suspension; and the remainder falls to the grates where the combustion process is completed.



9-B-1-3

References: *Steam Plant Operation*
Combustion Engineering
Elementary Steam Power Engineering

Assignment:

1. Discuss why you feel stokers were developed.
2. What are the three general types of stokers?
3. What duties or functions must be performed by a stoker?
4. Why is it impossible to burn a caking type coal on a traveling grate stoker?
5. Why is ash content so important in a chain grate stoker?
6. Discuss the difference in volume between a hand-fired and a stoker-fired furnace.

Objectives:

1. Be able to describe the development of pulverizers.
2. Be able to describe the types of pulverizers.

Information: We atomized oil so that more oil was put into closer contact with the oxygen in the air for complete combustion. Well, we pulverize coal for the same reason. The coal is pulverized to the consistancy of face powder; it is then introduced into the firebox where it is burned in suspension.

Engineers have worked with pulverized coal as early as 1824. In 1890 Rudolf Diesel tried to use pulverized coal in his diesel engine. During this time, the cement industry was achieving some success with pulverized coal in its cement kilns. They had experience in grinding and pulverizing the materials used in the manufacture of cement. Thomas A. Edison was instrumental in making improvements that increased the output and efficiency of cement kilns firing pulverized coal. However, it wasn't until after World War I that great strides were made, when electric generating stations became involved.

The pulverizer or mill is used to achieve the grinding or powdering of the coal making it suitable for combustion. The basic principles involved in size reduction are crushing, impact, and attrition. The pulverizers may use one, two, or all three of these methods according to their design.

Pulverizers are also classified as to their speed as follows:

1. High speed (over 300 r.p.m.) impact pulverizer: Coal is pulverized as result of impact of hammers on large pieces of coal and attrition of smaller pieces on each other and the grinding surface of the mill.
2. Medium speed (between 70 and 300 r.p.m.) ball and face: Coal is pulverized as result of crushing and attrition with some impact. The pulverizing action takes place between two surfaces, one rolling over the other.
3. Slow speed (under 70 r.p.m.) ball or tube mill: Pulverizing takes place due to the action of the impact of falling balls on the coal. Crushing takes place as balls roll over each other and the liner, and as the coal slides over other coal as well as the liner.

When selecting coal for pulverizing, you must know:

1. Grindability
2. Moisture content
3. Rank
4. Volatile matter
5. Ash content

Most of this information is obtained from a proximate analysis.

References: *Steam Plant Operation*
Combustion Engineering
Elementary Steam Power Engineering

Assignment:

1. Why are engineers so interested in the development of pulverized coal?
2. Why was the cement industry the first to achieve success in coal pulverization?
3. What three basic principles are involved in coal reduction?
4. How are pulverizers classified?
5. What data must the engineer have before he can select coal for pulverizing?
6. What are the advantages of a pulverized fuel plant?
7. What are the disadvantages involved in using pulverized coal?

Objectives:

1. Be able to explain the purpose of gas piping.
2. Be able to describe the types of valves and controls used.

Information: Natural gas has become very popular as a fuel for high-pressure boilers because of the introduction of strict, anti-pollution laws. It is highly explosive and toxic, and does require skillful, intelligent handling. All gas lines should be color coded for quick identification, so that they can be tested for leaks. In the event of a gas leak, you don't have time to trace lines; it would waste valuable time. In our school plant, the gas lines are large; this is due to the low pressure and large volume of gas.

We have both high-pressure gas service and low-pressure gas service in our school plant, so it will be necessary for us to discuss them one at a time:

The low-pressure gas service is used on our high-pressure, gas-fired boiler. The boiler is semi-automatic which means that the pilot must be lighted manually; then the manual reset valve must be opened by hand. After the burner ignites, the controls may then be switched to automatic operation and the boiler will be under the control of the pressure-trol and the modulating pressure-trol. Using Figure 9-C-1-1 let's go through a light off sequence:

1. Close the main switch that controls power to all electric controls on the boiler.
2. Open the pilot gas cock (1).
3. Push pilot ignition button on the control board, and the pilot will light.
4. Open the manual gas cock (2).
5. Lift the handle on the manual reset safety shutoff valve (5).

The gas now flows up to the balanced zero reducing governor (6) where it is reduced to zero pressure as it passes through the governor. The gas pressure switch, or vaporstat, (7) will complete an electric circuit as soon as it "proves" gas pressure to the governor. The circuit then starts the forced draft fan or blower (10). The motorized air control valve (11) is a slow moving electric motor (modulating motor) that operates a butterfly valve in the air line controlling the amount of air passing through. At initial light off, it will be in the low fire position which will only allow a small amount of air to pass through to the venturi (12). As the air passes through the venturi, it pulls the gas through the mixjector (9) which mixes the air and gas, and passes this mixture to the cage (13) where it is ignited by the pilot (4). And it passes through the block and holder (14) into the firebox. Secondary air is controlled by an adjustable ring that is located on the front of the burner cage. Once the burner has ignited, it can be turned over to automatic operation as was mentioned at the beginning.

Looking back:

1. Main switch-controls power to all electric controls.
2. Pilot gas cock – manual shutoff to pilot.
3. Manual gas cock – manual shutoff of all gas to boiler
4. Pilot solenoid valve – opens when pilot swtich is turned on allowing gas to flow through pilot gas line where it is ignited by spark from ignition transformer.
5. Manual reset safety shutoff – valve controlling gas to governor; cannot be opened until pilot is established. Will close automatically if boiler goes low on water or if there is a pilot and main flame failure.
6. "O" reducing governor – reduces gas pressure 0 p.s.i. so that gas will lie dormant in line waiting for air to suck it from mixjector and deliver it to the burner.
7. Main gas solenoid valve – located between "0" reducing governor and mixjector. It is energized when vaporstat "proves" gas at inlet of governor.
8. Vaporstat – located before "0" reducing governor. As soon as it "proves" gas pressure at inlet side of governor, it will open main gas solenoid and start the forced draft blower.
9. Mixjector – where gas lies dormant after passing through "0" reducing governor and main gas solenoid.
10. Bryant flomixer – venturi where air pressure is converted to higher velocity and gas is drawn in to mix with it passing through to burner cage.
11. Butterfly valve – located in discharge line from blower to flomixer.
12. Modulating motor – controls butterfly valve opening and closing controlling high and low fire.

The high-pressure surface is used on our school plant low-pressure boiler. The boiler is fitted with a combination gas- or oil-fired burner. The firing cycle is controlled by the same programming clock used for oil firing. The gas line is equipped with:

1. Manual shutoff cock.
2. Pressure-reducing governor
3. Main gas solenoid valve.

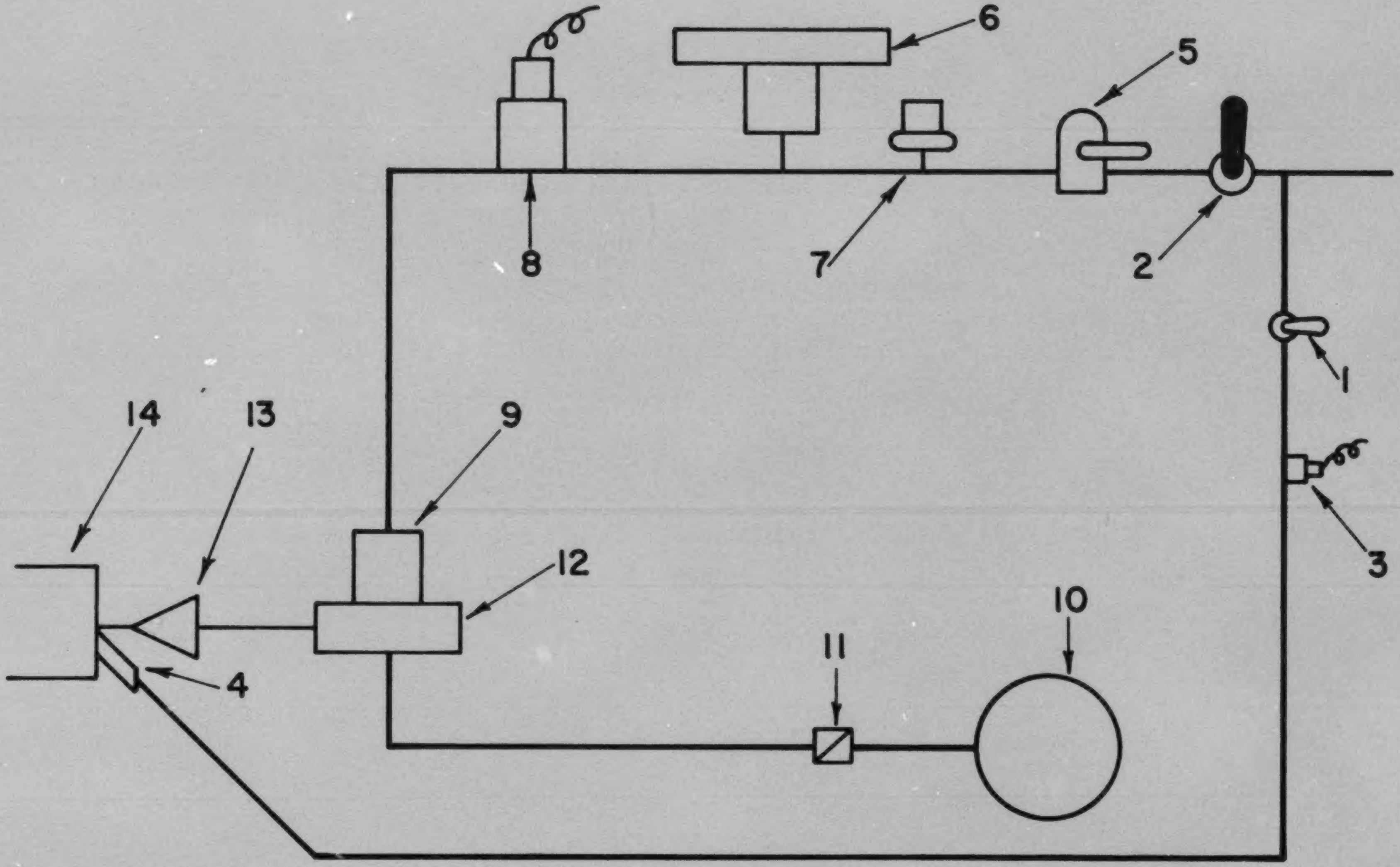
4. Slow opening gas valve so that it will light off in low fire.
5. Butterfly valve which is controlled by the modulating motor that controls high and low fire for gas and oil.

Changing from oil to gas only requires opening the manual gas cock and turning the selector switch to gas. The program clock will then put the boiler through a firing cycle – purge, pilot, ignition, and then control by pressure-trol and modulating pressure-trol.

References: *Manufacturers Data Sheet*
Low Pressure Boilers

Assignment:

1. Discuss why it is necessary to color code all gas lines.
2. What is the difference between automatic and semi-automatic boilers?
3. What must be done before a pilot can be lighted?
4. What is the purpose of a vaporstat in the gas system?
5. What purpose does the manual reset safety shutoff serve?
6. How much gas pressure is there in mixjector?
7. What does the butterfly valve control, and what controls the butterfly valve?
8. On the high-pressure service, what is the reason for a slow opening valve?
9. On the high-pressure gas service, what does the butterfly valve control, and what controls the butterfly valve?


6
5
8
7
2
1
3
14
13
9
12
10
11
4

9-C-1-1

Objectives:
1. Be able to explain the purpose of combustion controls.
2. Be able to explain how the on-off combustion control works.

Information: The purpose of combustion controls is to increase the safe and efficient operation of a boiler by regulating:
1. Fuel supply according to steam demand
2. Air supply
3. Ratio of air to fuel supply

There are three basic types of combustion controls.
1. On-off operation
2. Positioning
3. Metering

In this lesson we will only cover the on-off type. This combustion control is found on smaller types of package boilers. It consists of the following pieces of equipment.
1. Pressure control – This controls the operating range of the boiler. It starts and stops the burner on pressure demand.
2. Modulating pressure control – This controls high and low fire. A burner should always start on low fire and shut down on low fire.
3. Program clock – This controls the starting sequence of a burner.

When the load increases, the burner must supply more fuel to the firebox. This means more air is needed for complete combustion, and more gases of combustion must be released to the stack. Let's look at a typical plant setup. The operating range will be 85 p.s.i. to 100 p.s.i. When the pressure in the boiler drops to 85 p.s.i. the program clock will operate putting the burner through a firing cycle. The burner lights off in low fire, and the modulating pressure-trol will start to bring the burner up to high fire, by energizing the modulating motor through linkage the modulating motor is connected to the oil valve, primary air damper, and secondary air damper. As the burner passes from low to high fire, the air fuel ratio must change, and it must change together at the same time. When the boiler starts to pick up the plant load and the steam pressure starts to pick up or increase, the modulating pressure-trol will start to put the burner back towards the low fire position. The burner will modulate between high and low fire until the boiler reaches its cutout pressure — 100 p.s.i. The pressure-trol will shut the burner off, and the cycle will be repeated when the boiler calls for steam. The burner should always be running for longer periods than it is off. It should fire for about 30 minutes and be off for 5 minutes, not fire for 5 minutes and be off for 30 minutes, etc. This keeps the firebox from uneven cooling which would tend to cause spauling of brick work. This is done by proper setting of the pressure-trol and modulating pressure-trol.

References: *Steam Plant Operation*
Low Pressure Boilers
Elementary Steam Power Engineering

Assignment:

1. What is the purpose of combustion controls?
2. What do combustion controls regulate?
3. What does the pressure-trol do?
4. What is the function of the modulating pressure-trol?
5. Where are the pressure-trol and modulating pressure-trol found on a boiler, and how are they connected?
6. Why are siphons needed on pressure-trols and modulating pressure-trols?
7. What is meant by low fire, and why should a burner start up and shut down in low fire?
8. Why is it important to keep burners firing for longer periods than they are off?
9. Why can't the on-off combustion control be used in a generating plant?
10. Why must changes in fuel, primary air, and secondary air occur simultaneously?

Objectives:

1. Be able to explain the purpose and function of a temperature regulator.
2. Be able to explain the purpose and function of a pressure regulator.
3. Be able to explain the purpose and function of a pressure safety relief valve.

Information: Temperature regulation in a fuel oil system is usually done in one of two ways. Electric heaters can be used with the temperature of the oil being controlled by a thermostatic on-off switch. However, steam or hot water heaters are much more practical and cost less to operate. The temperature of the oil is controlled by a thermostatic control valve in the steam or hot water line. The valve has a capillary tube and bulb connected to a bellows. The bellows expands with a temperature rise tending to close the steam or water valve. In this manner it is possible to control the fuel oil temperature to within a few degrees for good atomization. It is also important to control the oil pressure in a fuel oil system because the amount of pressure needed for atomization differs in each type of system. The pressure is controlled by a valve that has a diaphragm and a control line connected between the control point and the diaphragm. A pressure increase in the system tends to close the valve. This type of control valve maintains a fairly constant pressure in the system.

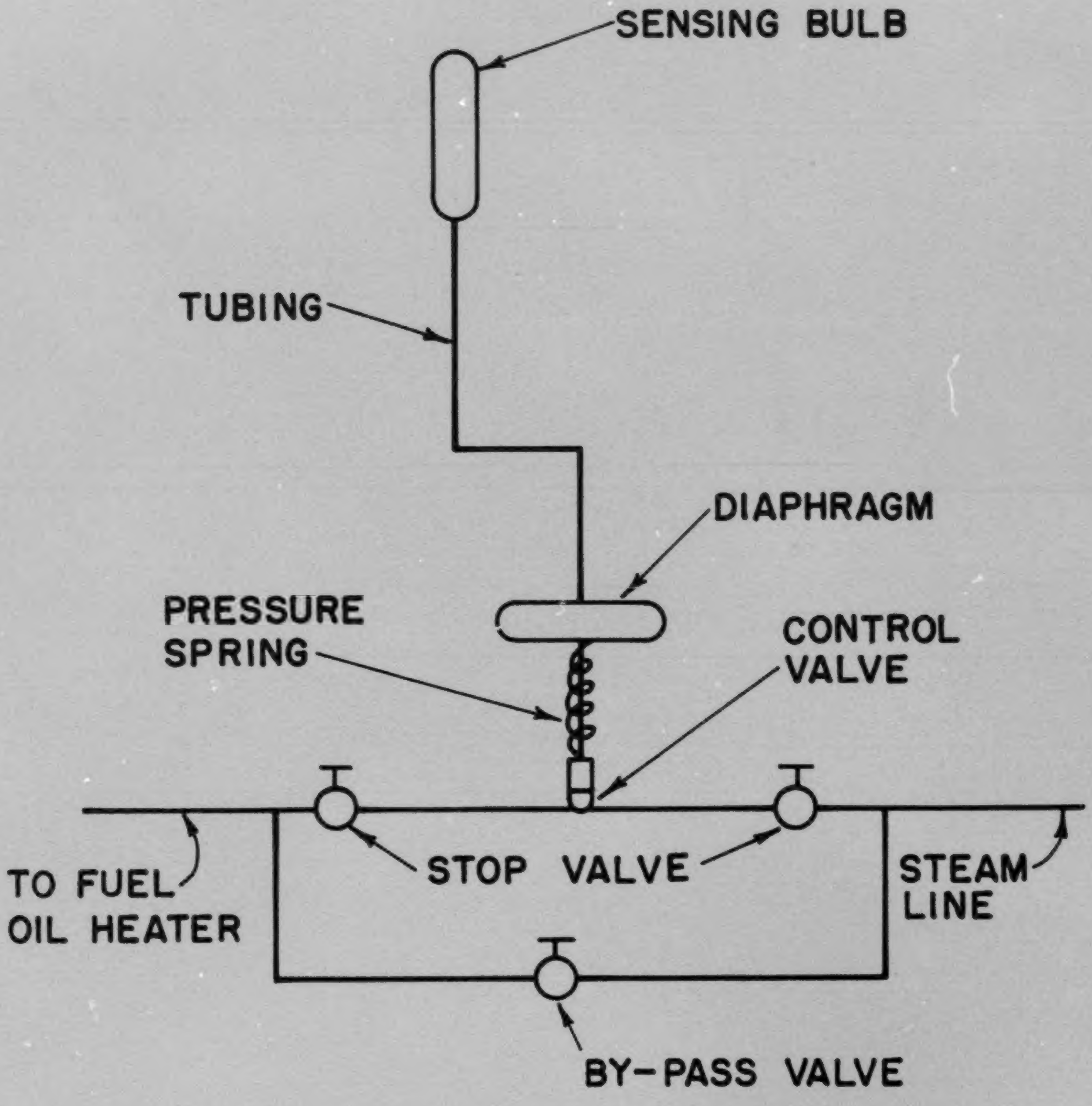
For safety and to conform with the A.S.M.E. Code as adopted in New Jersey, relief safety valves have to be installed at all points in the system where a pressure buildup could occur. This will be: (1) on the discharge side of the fuel oil pump; but it will be before the first valve (2) on all heaters to protect against pressure increase if oil is heated with inlet and outlet valves closed, and (3) at any other point where oil could be locked in and then heated. The regulation of temperature, pressure, and the relief of excess pressure is extremely important in a good fuel oil system. Proper temperature and pressure are essential for good combustion, and the pressure relief is needed for the safety of personnel and the plant.

References:

Steam Plant Operation
Elementary Steam Power Engineering

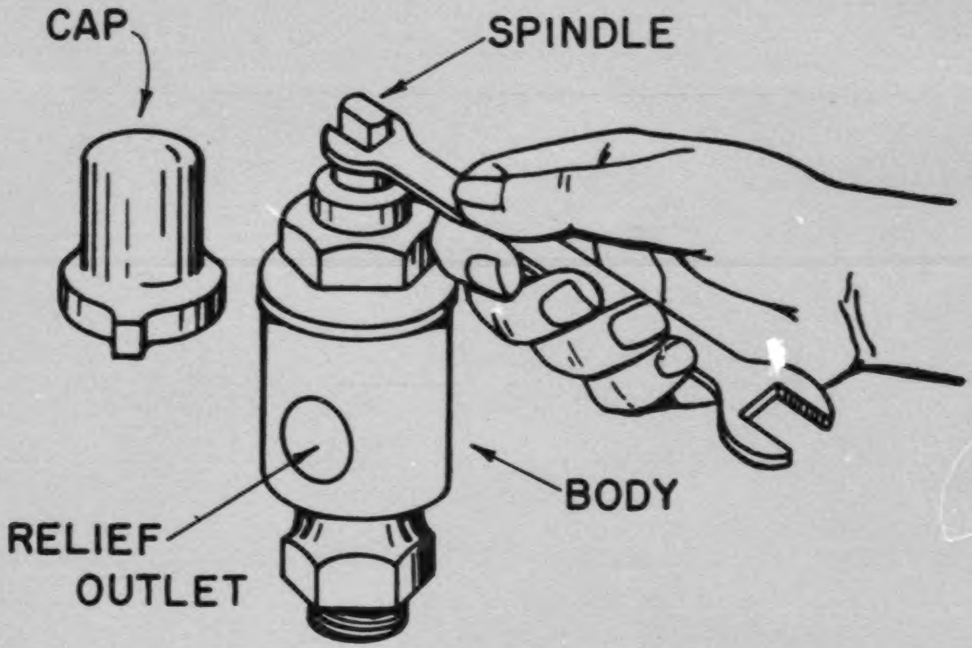
Assignment:

1. a. What is the purpose of a pressure regulating valve?
   b. How does it function?
2. a. What is the purpose of a temperature regulating valve?
   b. How does it function?
3. What is the purpose of a safety relief?
4. Where are safety reliefs found in the system?


SENSING BULB
TUBING
DIAPHRAGM
PRESSURE SPRING
CONTROL VALVE
TO FUEL OIL HEATER
STOP VALVE
STEAM LINE
BY-PASS VALVE

SCHEMATIC FUEL OIL
TEMPERATURE REGULATOR

9-D-2-1


CAP
SPINDLE
BODY
RELIEF OUTLET

ADJUSTABLE RELIEF VALVE

9-D-2-2

Objectives:

1. Be able to describe the purpose of a programer.
2. Be able to describe how a programer works.

The purpose of a programer is to put the burner through a firing cycle. It will control the operation of the blower, burner motor, ignition system, fuel valve, and modulator system in proper sequence. It will provide a suitable purge period before ignition and after burner shutdown. It is further designed to de-energize all fuel valves within 1 to 4 seconds upon loss of flame signal. The programer recycles automatically each time the operating or limit control closes or after a power failure, but it locks out and must be reset manually after any flame failure.

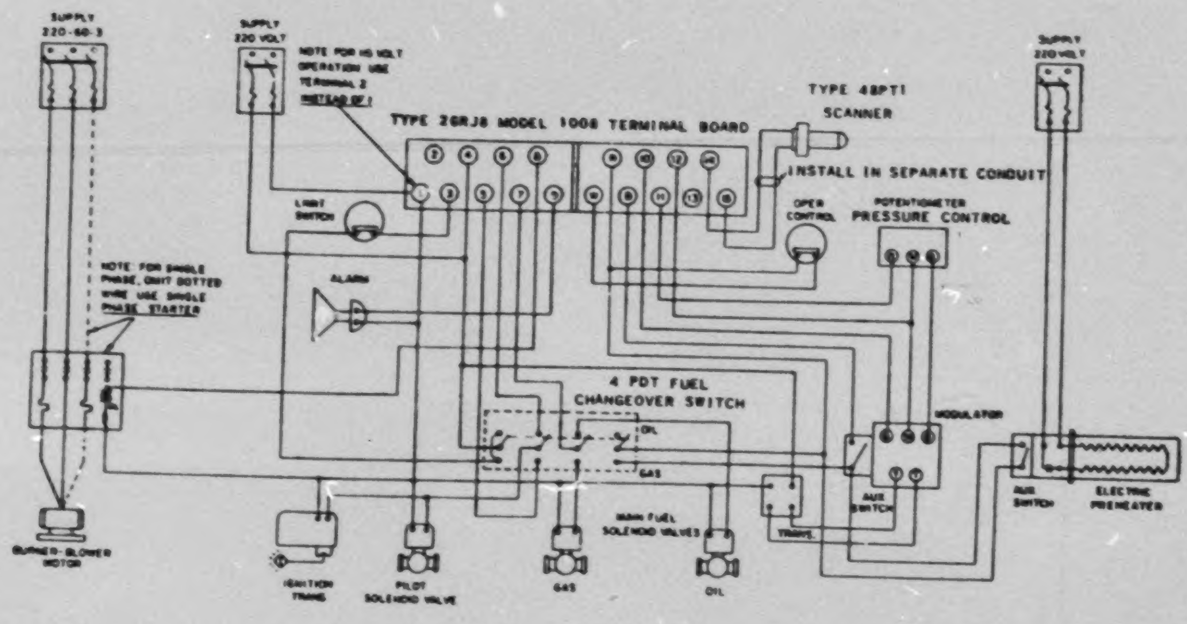
The following schematics and charts should be studied carefully. Figure 9-D-3-1 will show you the control wiring of the programer of No. 4 boiler in the school plant. Figure 9-D-3-2 shows a programing sequence and what relays are energized during the sequence of operation. The Figure 9-D-3-3 will help you identify the cam assembly and relays in the programer.

References: *Low Pressure Boilers*
Fireye Bulletin CPS 22

Assignment:

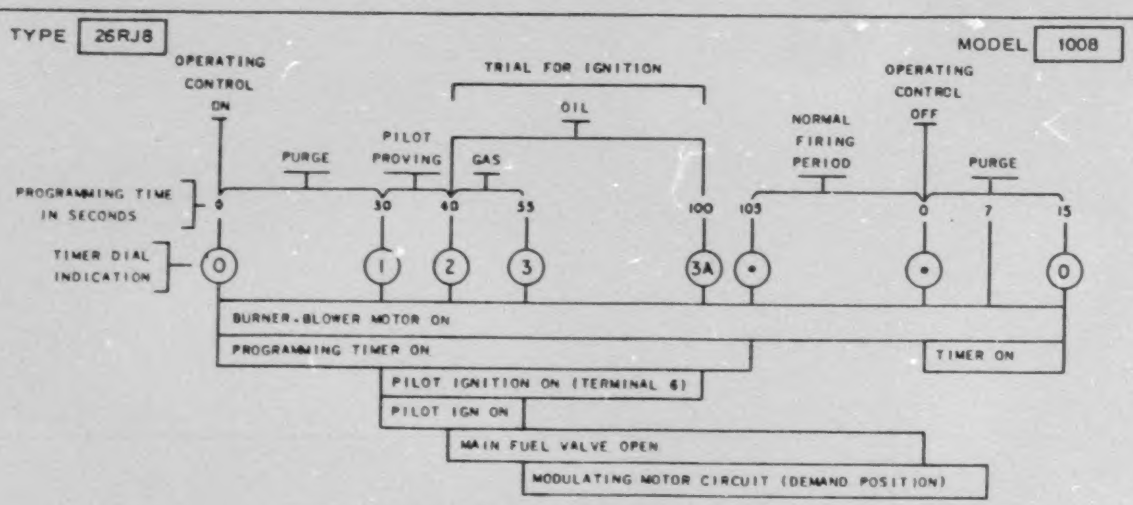
1. What is the purpose of the programer clock?
2. Describe how it puts the burner through a firing cycle.
3. What is meant by "proving" pilot?
4. What will happen to the main fuel valve if the pilot is not proven?
5. Describe the location and operation of the following:
   a. Master relay RL-1
   b. Flame relay RL-2
   c. Lockout switch RL-3
6. How long does it take for the programing timer to reach No. 2 on the timer indicator, and what is happening in the programing sequence?
7. What purpose does a post purge serve, and at what point in the sequence does it take place?

Automatic Combination Gas – Oil Burner Number 6 Oil Gas Electric Ignition


SUPPLY 220-60-3
SUPPLY 220 VOLT
NOTE FOR 110 VOLT OPERATION USE TERMINAL 2 INSTEAD OF 1
TYPE 26RJ8 MODEL 1008 TERMINAL BOARD
TYPE 48PT1 SCANNER
INSTALL IN SEPARATE CONDUIT
SUPPLY 220 VOLT
LIGHT SWITCH
OPER CONTROL
POTENTIOMETER PRESSURE CONTROL
NOTE: FOR SINGLE PHASE, OMIT DOTTED WIRE USE SINGLE PHASE STARTER
ALARM
4 PDT FUEL CHANGEOVER SWITCH
OIL
GAS
MODULATOR
AUX SWITCH
AUX SWITCH
ELECTRIC PREHEATER
TRANS.
BURNER-BLOWER MOTOR
IGNITION TRANS
PILOT SOLENOID VALVE
MAIN FUEL SOLENOID VALVES
GAS
OIL

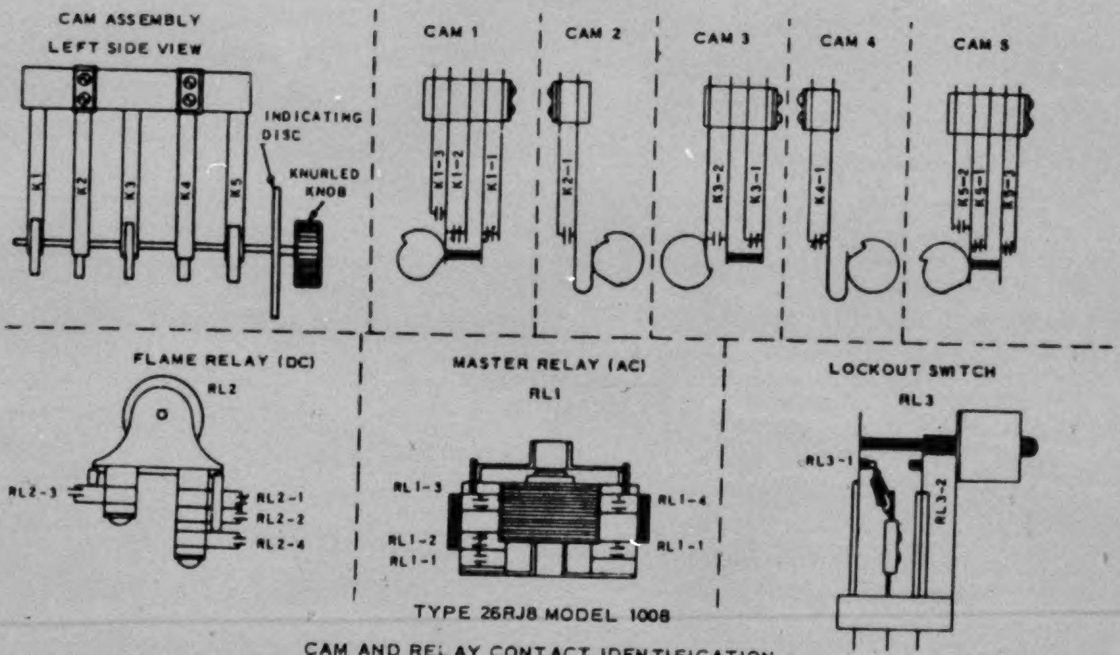
9-D-3-1

TIMER INDICATION	TIME IN SECONDS	EXTERNAL OPERATION	CONTACT OPERATION (FIG. 20 AND 21)
		STARTUP: Limit switch and operating control circuit *closes.*	
0	0	Burner/blower motor *starts.* Programming Timer *starts.* Modulator circuit is in *low fire* position.	Relay RL1 is *energized.* Contacts RL1-1, 3, and 4 *close*, RL1-2 *open.*
	12		Cam contacts K3-2 *close,* K3-1 *open.*
1	30	Pilot valve and ignition transformer *on.*	Cam contacts K2-1 *close.* Relay RL2 is *energized.* Contacts RL2-2, 3, and 4 *close,* RL2-1 *open.*
2	40	Main fuel valve *opens* providing pilot flame is detected.	Cam contacts K1-1, 2 *open,* K1-3 *close.*
3	55	Pilot *off* (if connected to Terminal 5). Modulator circuit switches to *operating* position.	Cam contacts K5-1, 3 *open,* K5-2 *close.*
3A	100	Pilot *off* (if connected to Terminal 6).	Cam contacts K2-1 *open.*
"dot"	105	Programming Timer *stops.* END OF STARTUP.	Cam contacts K4-1 *open.*
		NORMAL FIRING PERIOD	
		SHUTDOWN: Limit switch or operating control circuit *opens.*	
"dot"	0	Main fuel valve *closes.* Programming Timer *starts.*	Relays RL1 and RL2 are *deenergized.* Contacts RL1-1,3,4 *open,* RL1-2 *close.* RL2-2, 3, and 4 *open,* RL2-1 *close.*
	5		Cam Contacts K1-1, 2 *close,* K1-3 *open.*
	7	Modulator circuit switches to *low fire* position.	Cam Contacts K5-1, 3 *close,* K5-2 *open.*
0	15	Burner/blower motor shuts *off.* Programming Timer *stops.* END OF SHUTDOWN.	Cam Contacts K3-2 *open,* K3-1 *close.*


TYPE 26RJ8
MODEL 1008
OPERATING CONTROL ON
TRIAL FOR IGNITION
OIL
PILOT PROVING
PURGE
GAS
NORMAL FIRING PERIOD
OPERATING CONTROL OFF
PURGE
PROGRAMMING TIME IN SECONDS
0
30
40
55
100
105
0
7
15
TIMER DIAL INDICATION
0
1
2
3
3A
•
•
0
BURNER-BLOWER MOTOR ON
PROGRAMMING TIMER ON
TIMER ON
PILOT IGNITION ON (TERMINAL 6)
PILOT IGN ON
MAIN FUEL VALVE OPEN
MODULATING MOTOR CIRCUIT (DEMAND POSITION)

PROGRAMMING SEQUENCE WITH PILOT IGNITION

9-D-3-2


CAM ASSEMBLY
LEFT SIDE VIEW
K1
K2
K3
K4
K5
INDICATING DISC
KNURLED KNOB
CAM 1
K1-3
K1-2
K1-1
CAM 2
K2-1
CAM 3
K3-2
K3-1
CAM 4
K4-1
CAM 5
K5-2
K5-1
K5-3
FLAME RELAY (DC)
RL2
RL2-3
RL2-1
RL2-2
RL2-4
MASTER RELAY (AC)
RL1
RL1-3
RL1-2
RL1-1
RL1-4
RL1-1
TYPE 26RJ8 MODEL 1008
LOCKOUT SWITCH
RL3
RL3-1
RL3-2

CAM AND RELAY CONTACT IDENTIFICATION

9-D-3-3

Objective: 1. Be able to explain the basic principles of combustion and the combustion equations.

Information: Combustion may be defined as the rapid union of oxygen with an element or compound which will result in the evolution of heat. An example of this is when the elements in a fuel combine with the oxygen in the air to produce heat. The elements in the fuel are:

a. Carbon
b. Sulphur
c. Hydrogen
d. Oxygen
e. Nitrogen

Oxygen will support combustion, but it is not a combustible by itself. Nitrogen is neither combustible nor a supporter of combustion. Carbon, hydrogen, and sulphur are the combustibles in a fuel; they combine with the oxygen from the air to form compounds of combustion. When carbon combines with oxygen, it forms a compound of carbon monoxide or carbon dioxide. This can be shown with the following combustion equations:

$$2C + O_2 \Rightarrow 2CO + \text{Heat}$$

$$C + O_2 \Rightarrow CO_2 + \text{Heat}$$

When sulphur combines with oxygen, it forms sulphur dioxide:

$$S + O_2 \Rightarrow SO_2 + \text{Heat}$$

Hydrogen combines with oxygen to form water vapor as follows:

$$2H_2 + O_2 \Rightarrow 2H_2O + \text{Heat}$$

The above reactions are taking place in a furnace during the burning of a fuel provided there is sufficient air (oxygen) to burn to completion.

Reference: *Steam Plant Operation*

Assignment:

1. What elements in a fuel will combine with oxygen during the combustion process?
2. What elements will not combine with oxygen?
3. Show the combustion equations for the combustion process of a fuel.
4. What are the end products of combustion?
5. How would you know if you were burning a fuel to completion?

Objectives:

1. Be able to describe the types of combustion taking place in the furnace of a boiler.
2. Be able to describe why it is necessary to be able to control the combustion process.

Information: In order to understand combustion and what we are trying to accomplish when burning fuel, it is necessary to discuss some terminology.

1. **Primary air** – Air that will control the rate of combustion. It is the amount of fuel you can burn.
2. **Secondary air** – Air that will control the combustion efficiency. It controls how well you burn the fuel.
3. **Excess air** – Air that is applied to the boiler that is extra. It is above the theoretical amount needed.

Combustion may be classified or broken down into three catagories:

1. **Perfect combustion** – Burning all the fuel with only the theoretical amount of air supplied. This can never be achieved in a boilerroom. It is only possible in a lab where the combustion process can be carefully controlled.
2. **Complete combustion** – Burning of all the fuel with the proper amount of excess air supplied. This is what we strive for in a boilerroom. We want to burn all the fuel so that we do not add pollutants to our already polluted atmosphere.
3. **Incomplete combustion** – All the fuel is not burned for one reason or another; it results in the formation of soot and smoke.

It is the operator's responsibility to be thoroughly familiar with his equipment and the combustion process. Many states have passed laws limiting the amount of sulphur contained in fuel oil. This cuts down on the sulphur dioxide that is discharged with the gases of combustion. By carefully controlling the combustion process, we eliminate soot and smoke from being discharged by our stack. Fly ash, small light particles of ash that normally are discharged with the combustion gases, is handled by fly ash precipitators. These precipitators trap and hold it so that it may be disposed of.

Fines are being levied against buildings that do not conform to the anti-pollution laws. It may be against the law to discharge smoke, soot, or fly ash into the atmosphere. The fines can run into hundreds of dollars in many states.

References: *Steam Plant Operation*
Air Pollution Manual

Assignment:

1. Define the following:
    a. Primary air
    b. Secondary air
    c. Excess air
    d. Perfect combustion
    e. Complete combustion
    f. Incomplete combustion
2. Why do you think perfect combustion is not possible in a boilerroom?
3. What would result if you were using more excess air than necessary?

Objectives:

1. Be able to explain the combustion process.
2. Be able to explain what is needed for complete combustion of oil, gas, and coal.

In Assignment 10-B-1 on types of combustion, we discussed:

a. Primary air
b. Secondary air
c. Excess air
d. Perfect combustion
e. Complete combustion
f. Incomplete combustion

We also said that our goal is complete combustion, which is the burning of all the fuel with the proper amount of excess air. In order to accomplish this, we need four things. You can best remember them by the word, M.A.T.T.

M – Proper *mixture* of air and fuel. The ratio of air and fuel must be controlled at all firing rates. High fire when you burn the maximum amounts of oil would require more air than when the burner is low fire.

A – Proper *atomization* of fuel. This breaks up fuel into small particles to bring it in more intimate contact with the air. It improves combustion.

T – Proper *temperature*. Air, fuel, and zone temperature must be maintained in order to achieve complete combustion.

T – *Time* to complete combustion. The combustion process must be completed before the gases of combustion come in contact with the heating surface.

Note: You should remember that the heating surface is where there is water on one side and gases of combustion on the other.

If the gases of combustion come in contact with the heating surface before combustion is complete, they will cool and cause the formation of soot and smoke.

We spoke about the air needed for combustion of fuel. It is the oxygen in the air that is needed. Air is made up of approximately 20% oxygen and 80% nitrogen, nitrogen does not enter the combustion process. Let's see how the combustion process takes place in an actual furnace.

Coal when fired on a grate is porous enough to allow air to pass through the coal bed, thus giving intimate contact between the fuel and the air. With some types of coal, it is necessary to introduce air over fire to obtain complete combustion, or the proper air-fuel ratio. The temperature within the furnace is maintained at approximately 2750°F. In order to have sufficient time to complete combustion, it is necessary to have the correct furnace volume. When coal is burned in suspension, such as in pulverized coal installations, heated air is introduced into the furnace with the coal. The remaining air necessary for complete combustion is blown in around the burner to insure proper fuel-air ratio. The temperature of furnaces that burn coal in suspension is approximately 3000°F. When burning coal in this manner, the furnace volume is relatively large due to the high rate of combustion taking place. Fuel oil is burned in much the same way as pulverized coal. Oil is introduced in a conical patterned spray with air blown in around it. The correct fuel-air ratio can be easily maintained. The furnace temperature is somewhat lower than with coal; it is usually about 2500°F. Gas can be readily mixed with air to obtain proper air-fuel ratio and intimate contact. With the proper furnace volume, it is only necessary to maintain proper furnace temperature which is slightly below that of oil.

As you can see, complete combustion must satisfy all four conditions:

Mixture
Atomization
Temperature
Time

Reference: *Steam Plant Operation*

Assignment:

1. What is meant by complete combustion?
2. Discuss what is meant by M.A.T.T.
3. What will result if the gases of combustion come in contact with the heating surface before the combustion process is completed?
4. Why must the oil be atomized?
5. What is the chemical composition of air? What happens to these chemical elements during the combustion process?
6. Explain in your own words what takes place in a furnace after the fuel is introduced.

Objectives:
1. Be able to explain the purpose of combustion gas analyzers.
2. Be able to explain how a combustion gas analyzer functions.

Information: From your previous units, you should have a working knowledge of combustion and what is needed for complete combustion, but just to play it safe, let's go over a few terms.

Perfect combustion – the burning of all the fuel using only the theoretical amount of air. This can never be achieved in a boilerroom.

Complete combustion – the burning of all the fuel using the proper amount of excess air. This is what we try to do in industry as well as in our boilerroom.

Incomplete combustion – when all the fuel is not burned for one reason or another.

CO_2 – carbon dioxide which in flue gas is a sign of complete combustion.

CO – carbon monoxide which in flue gas is a sign of incomplete combustion.

O_2 – oxygen which would be a sign of excess air.

Now it stands to reason that there must be some way to determine just how efficiently we can burn our fuel. This can be done by analyzing our flue gases with an analyzer to determine the following:

1. Amount of CO_2 (carbon dioxide)
2. Amount of CO (carbon monoxide)
3. Amount of O_2 (oxygen)

The simplest flue gas analyzer is one that measures only the percentage of carbon dioxide (CO_2) in the flue gas. It operates in the following manner:

1. A sample of flue gas is put into the analyzer.
2. The analyzer is inverted so that the sample can readily mix with a carbon dioxide absorbing solution.

3. The absorption of the gas into the solution increases the volume of the solution and gives a direct reading in percentage of CO_2.

If the percentage of carbon dioxide and the flue gas temperature is known, it is possible to find the combustion efficiency on the slide rule calculator that is supplied with the analyzer.

A more complete gas analysis can be taken with an analyzer that measures carbon dioxide, carbon monoxide, and oxygen. It functions in the following way:

1. A sample of flue gas is taken into a burette, and the volume is carefully measured. Let us say that the volume is 100 CC.
2. The gas is then brought into contact with a CO_2 absorbing chemical which removes the CO_2 from the sample.
3. The sample is then measured, and the difference in volume is the amount of CO_2 that was in the sample originally.

   $$100 \text{ c.c.} - 87 \text{ c.c.} = 13\% \, CO_2$$
4. The next chamber contains a chemical that absorbs oxygen; the sample is allowed to pass through while the oxygen is absorbed.
5. The sample is again measured to determine the amount of O_2.

   $$87 \text{ c.c.} - 83 \text{ c.c.} = 4\% \, O_2$$
6. The last chamber absorbs the carbon monoxide and gives us our last reading.

   $$83 \text{ c.c.} - 81 \text{ c.c.} = 2\% \, CO$$
7. The amount that remains is the nitrogen (N_2) that was in the air used for combustion.

Our final analysis would be:

carbon dioxide	13%
oxygen	4%
carbon monoxide	2%
nitrogen	81%

From this analysis, it is possible to find the amount of excess air that is to be used in the combustion process.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. What is CO_2? What does it mean in your flue gas?
2. What is CO? What does it mean in your flue gas?
3. What analyzer measures only CO_2?
4. Describe in detail how you use a CO_2 analyzer.
5. How would you be able to obtain a complete analysis of your flue gas? Explain in detail.

Objectives:

1. Be able to use the results from a flue gas analysis.
2. Be able to calculate excess air used in the combustion process.
3. Be able to determine the correct amount of excess air to have when burning coal, oil, or gas.

Information: From the results of the flue gas analysis found in the last lesson, it is possible to find the percentage of excess air being used in the combustion process. The percentage of excess air over the theoretical requirements can be calculated by the following formula:

$$\% \text{ of excess air} = \frac{O_2 - \frac{1}{2}CO}{.263N_2 + \frac{1}{2}CO - O_2} \times 100$$

Let us find the percentage of excess air using the following flue gas analysis results:

Gas	No. 1	No. 2
CO_2	13%	12%
O_2	4%	6%
CO	2%	.6%
N_2	81%	81.4%

Example 1: % of excess air

$$\begin{aligned} &= \frac{O_2 - \frac{1}{2}CO}{.263N_2 + \frac{1}{2}CO - O_2} \times 100 \\ &= \frac{4 - (\frac{1}{2} \times 2)}{(.263 \times 81) + (\frac{1}{2} \times 2) - 4} \times 100 \\ &= \frac{4 - 1}{21.303 + 1 - 4} \times 100 \\ &= \frac{300}{18.303} \\ &= 16.39\% \end{aligned}$$

Example 2: % of excess air

$$\begin{aligned} &= \frac{O_2 - \frac{1}{2}CO}{.263N_2 + \frac{1}{2}CO - O_2} \times 100 \\ &= \frac{6 - (\frac{1}{2} \times .6)}{(.263 \times 81.4) + (\frac{1}{2} \times .6) - 6} \times 100 \\ &= \frac{6 - .3}{21.4082 + .3 - 6} \times 100 \\ &= \frac{570}{15.7082} \\ &= 36.28\% \end{aligned}$$

The amount of excess air needed will depend to a large degree upon the type of fuel being used and how it is being burned.

Coal burned on a grate will require 50% to 75% excess air. Coal burned in suspension as in a pulverized coal burner will require 20% to 40% excess air. Oil will need 10% to 30% excess air, and natural gas will need only 5% to 10% excess air.

Remember, these are average values and good combustion will still depend upon M.A.T.T.

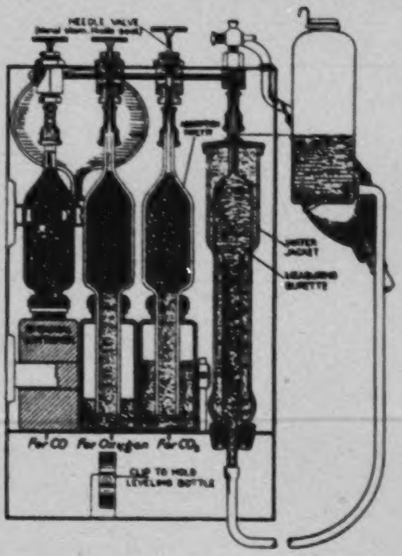
References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. What is the value of the results obtained from a flue gas analysis?
2. Find the percentage of excess air from the following data:

Gas	a.	b.	c.
CO_2	13.5%	15.2%	13.7%
O_2	5.5%	4.7%	3.5%
CO	0.0%	0.0%	1.8%
N_2	81.0%	80.1%	81.0%

3. What are the average values of excess air needed to burn coal, oil, and gas?


NEEDLE VALVE
WATER JACKET
MEASURING BURETTE
For CO
For Oxygen
For CO₂
CLIP TO HOLD LEVELING BOTTLE

10-D-1

Objectives:

1. Be able to describe how the combustion of oil takes place in a steam boiler furnace.
2. Be able to describe how the combustion of coal takes place in a steam boiler furnace.
3. Be able to describe how the combustion of gas takes place in a steam boiler furnace.

Information: The combustion of oil in a furnace depends upon the burner being able to deliver the correct quantity of oil, properly atomized and at the correct temperature, for burning. The air is introduced in a definite rotary fashion to mix with the oil in sufficient quantities, for complete combustion. The furnace temperature must be high enough to allow the combustion process to go to completion (usually 2500°F.). The volume of the furnace must be large enough for the complete combustion of all the gases before they enter the first pass or touch the heating surfaces of the boiler.

When burning coal, there are two possible ways it can be accomplished – on a grate or in suspension. Hard or anthracite coal is burned on grates with a fuel bed 2 to 5 inches deep. Air is introduced under the fuel bed and is forced through it. Combustion is completed just above the fuel bed. The greatest difficulty encountered is when holes are allowed in the fuel bed; then the air will pass through without combining with the fuel.

Soft coal, or bituminous coal, when burned on grates has a much thicker fuel bed than hard coal; it requires air to be introduced over the fire as well as under it. Because of the large amount of gases that are released from the fuel bed and the combustion that is taking place over the bed, a much larger air space is needed over the fire of a soft coal fire than a hard coal fire. The proper temperature has to be maintained in both cases to have complete combustion. When burning bituminous coal in suspension, it first has to be pulverized into a fine dust. The dust is mixed with heated air as it passes through the pulverizer; then it is blown into the furnace to burn in suspension. Sufficient secondary air is introduced to complete combustion. Temperatures are relatively high in this furnace. If combustion is not completed before reaching the first pass, slagging of the tubes could result. The furnace volume is large because of the high rate of combustion. Gas burners are of two basic types – air mixes with the gas outside the furnace or inside the furnace. But in both types, a proper gas-air ratio is maintained, and good combustion is obtained with a correct furnace temperature: the volume of the furnace must be large enough to allow complete combustion before the first pass.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. How is oil burned in a furnace (in detail)?
2. How is coal burned in a furnace (in detail) for both soft and hard coal?
3. Describe what happens during the combustion of gas in a furnace.

Furnace Volume — Assignment 10-E-2

1. Be able to describe the importance of proper furnace volume on combustion.

Objectives:

1. Be able to describe the importance of proper furnace volume on combustion.
2. Be able to determine the amount of furnace volume needed for a given boiler output.

Information: The design and shape of a boiler furnace depends upon the type of fuel that is being burned. Other factors to be taken into consideration are:

1. Natural or mechanical draft
2. Refractory or water-cooled furnaces
3. Rate of heat released from fuel

In all cases and under all load conditions the fuel must complete combustion within the furnace space. When oil is fired under natural draft conditions, 1 cu. ft. of furnace volume is needed per rated boiler horsepower. Only .75 cu. ft. of furnace volume is needed when mechanical draft is used.

Stoker firing of coal with a refractory furnace requires a furnace volume of 2.25 cu. ft. per rated boiler horsepower. A furnace with complete water-cooled walls would need only 1.5 cu. ft. These figures are average values because there are many types of stokers in use.

Pulverized coal without a water-cooled furnace requires 2.5 cu. ft. per rated boiler horsepower as compared with 1.4 cu. ft. for a water-cooled furnace.

A natural gas furnace required 1.75 to 2.00 cu. ft. of furnace volume per rated boiler horsepower. Furnace efficiency is affected by furnace volume and the amount of heat that can be released within that volume per hour.

References:

Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. Why does the furnace volume differ in various boilers?
2. How much volume is needed when burning:
    a. Oil
    b. Gas
    c. Coal
3. In boilers that use more than one fuel, what would determine furnace volume?
4. What should be the furnace volume on the No. 3 boiler in the school plant?

Pounds of Air Per Pound of Fuel — **Assignment 10-E-3**

Objectives:

1. Be able to calculate the theoretical amounts of air needed per pound of fuel.
2. Be able to calculate the theoretical amounts of oxygen needed per pound of fuel.

Information: The chemical composition of a fuel is basically:

nitrogen
oxygen
carbon
ash
sulphur
hydrogen

If an ultimate analysis of the fuel is used, the percentage of each element in the fuel can be found. From this analysis and the use of the following formula the pounds of air needed per pound of fuel may be found.

$$\text{lbs air/lbs. fuel} = 11.53C + 34.56(H - 0/8) + 4.32S$$

Note: This is the theoretical amount of air required. It is necessary to provide excess air to have complete combustion. The percent of excess can be found by the formula used in Assignment 10-D-1-M1.

Once the pounds of air per pound of fuel is known, you can find the pounds of oxygen present by dividing by 4.32.

Example: The ultimate analysis of a fuel is as follows:

carbon	70%	oxygen	8%
hydrogen	7%	sulphur	2%
nitrogen	5%	ash	8%

Find:

a. pounds of air/pound of fuel
b. pounds of oxygen

$$\begin{aligned}\text{lbs. air/ lbs. fuel} &= 11.53C + 34.56\left(H - \frac{\text{Oxygen}}{8}\right) + 4.32S \\ &= 11.53 \times .7 + 34.56\left(.07 - \frac{.08}{8}\right) + 4.32 \times .02 \\ &= 8.071 + .02419 + .0864 \\ &= 8.182 \text{ pounds of air}\end{aligned}$$

4.32 lbs air = 1 lb oxygen

$$\frac{8.182}{4.32} = 1.89 \text{ lbs of oxygen}$$

Procedure: After having read the information and studied the sample problem, do the following assignment.

Assignment: 1. The ultimate analysis of a fuel is as follows:

carbon	65%	oxygen	11%
hydrogen	6%	sulphur	4%
nitrogen	2%	ash	12%

Find: a. lbs. of air/lbs fuel
b. lbs. of oxygen

2. The ultimate analysis of a fuel is as follows:

carbon	61.5%	oxygen	6.2%
hydrogen	6.8%	sulphur	5.6%
nitrogen	3.4%	ash	1.1%

Find: a. lbs of air/lbs of fuel
b. lbs of oxygen

3. The ultimate analysis of a fuel is as follows:

carbon	85%	oxygen	5%
hydrogen	5%	sulphur	1%
nitrogen	2%	ash	2%

Find: a. lbs of air/lbs of fuel
b. lbs of oxygen

4. The ultimate analysis of a fuel is as follows:

carbon	88.86%	oxygen	1.95%
hydrogen	2.04%	sulphur	.35%
nitrogen	.9%	ash	5.9%

Find: a. lbs of air/lbs of fuel
b. lbs of oxygen

5. A plant is using a fuel that requires 14.5 pounds of air per pound of fuel. It burns 780 pounds of fuel per hour.
Find: a. lbs of air needed
b. lbs. of oxygen needed
6. If 20% excess air is needed in the above problem, what are the actual air and oxygen requirements?

Pounds of Steam Per Unit of Fuel — Assignment 10-E-4

Objectives:

1. Be able to calculate the pounds of steam generated per unit of fuel.
2. Be able to explain the purpose for calculating the pounds of steam per unit of fuel.
3. Be able to explain the reasons for maintaining a running record of the pounds generated per unit of fuel.

Information: During the day to day operation of a steam generating plant, it is not always possible to obtain a flue gas analysis at any given time. This is true even though some plants do have continual CO_2 and O_2 recorders. But even if it was possible to obtain the flue gas analysis, it is still only going to give you the condition of the combustion process.

A much simpler analysis that will consider overall boiler performance is in practice today. The number of pounds of steam that is generated from a boiler over a given period of time is divided by the amount of fuel used during that period. It could be in pounds of steam per gallon of oil, pounds of steam per pound of coal, or even pounds of steam per 100 cu. ft. of gas. With a day to day comparison it is possible to determine boiler performance. If the values start to drop, you then have to find out if it is due to combustion or heat transfer within the passes. This method is only effective for steam generating units with relatively constant feed-water temperatures.

In a coal-fired installation the reading from the coal scale is read every 8 hours, and the steam generated is read on the steam flow integrator at the same time.

$$\frac{\text{Pounds of steam}}{\text{Pounds of coal}} = \frac{\text{Total steam/8 Hrs.}}{\text{Total coal/8 Hrs.}}$$

When using oil,gallons are used instead of pounds of fuel; they are read directly from the fuel oil meter.

$$\frac{\text{Pounds of steam}}{\text{Gallons of oil}} = \frac{\text{Total steam/8 Hrs.}}{\text{Total oil/8Hrs.}}$$

With gas the calculations are based per 100 cu. ft.

$$\frac{\text{Pounds of steam}}{\text{100 cu. ft. of gas}} = \frac{\text{Total steam/8 Hrs.}}{\text{Total cu. ft./100 gas/8 Hrs.}}$$

It is also useful to find out the pounds of steam generated per unit of fuel over one-hour periods on minimum and maximum loads.

By maintaining a running record of the daily pounds of steam generated per unit of fuel, it is possible to determine daily boiler performance, which has a direct bearing on boiler efficiency.

Note: Do not make comparisons with other steam generating units unless feed-water temperature, steam pressure, and temperature are the same.

Reference: *Steam Plant Operation*

Assignment:

1. Why do you think it is necessary to know how to find the pounds of steam generated per unit of fuel?
2. How do you find the pounds of steam generated per pound of fuel?
3. Why is it important to maintain a daily record of steam generated compared to fuel used?
4. Explain what steps you would take to determine what the problem was if the pounds of steam per unit of fuel dropped down.

Differential Pressure Flowmeter — Assignment 11-A-1

Objectives:

1. Be able to describe how a differential pressure flowmeter functions.
2. Be able to describe how a differential pressure flowmeter is constructed.

Information: Flowmeters are used to determine the rate of flow, which is the amount of fluid that flows past a given point at any given instant. They are used for air, water, steam, oil, gases, and a variety of other fluids. In order to measure rate of flow by differential pressure, there must be a method of creating two different pressures. This can be done by placing a restriction in the pipeline to force the fluid through a reduced area. There are three ways in which this is done. The simplest pipeline restriction for flow metering is the orifice plate which is a thin, circular metal plate with a hole in it. Depending upon the fluid to be measured, this will determine the kind of orifice plate to be used.

A second more accurate method is the use of a Venturi tube, which is a specially shaped length of pipe resembling two funnels joined at their smaller openings. This method is used for large pipelines. It is more expensive and difficult to install. A third method is the flow nozzle, which is half of a Venturi tube; it is not as expensive, and it is not difficult to install.

To better understand the factors that are involved in the construction and function of a differential pressure flowmeter, we should review the following terminology.

1. **Pressure** – force per unit of area
2. **Density** – weight per unit of volume
3. **Viscosity** – internal resistance of a fluid to the flow
4. **Velocity** – speed in the direction of the flow of a fluid

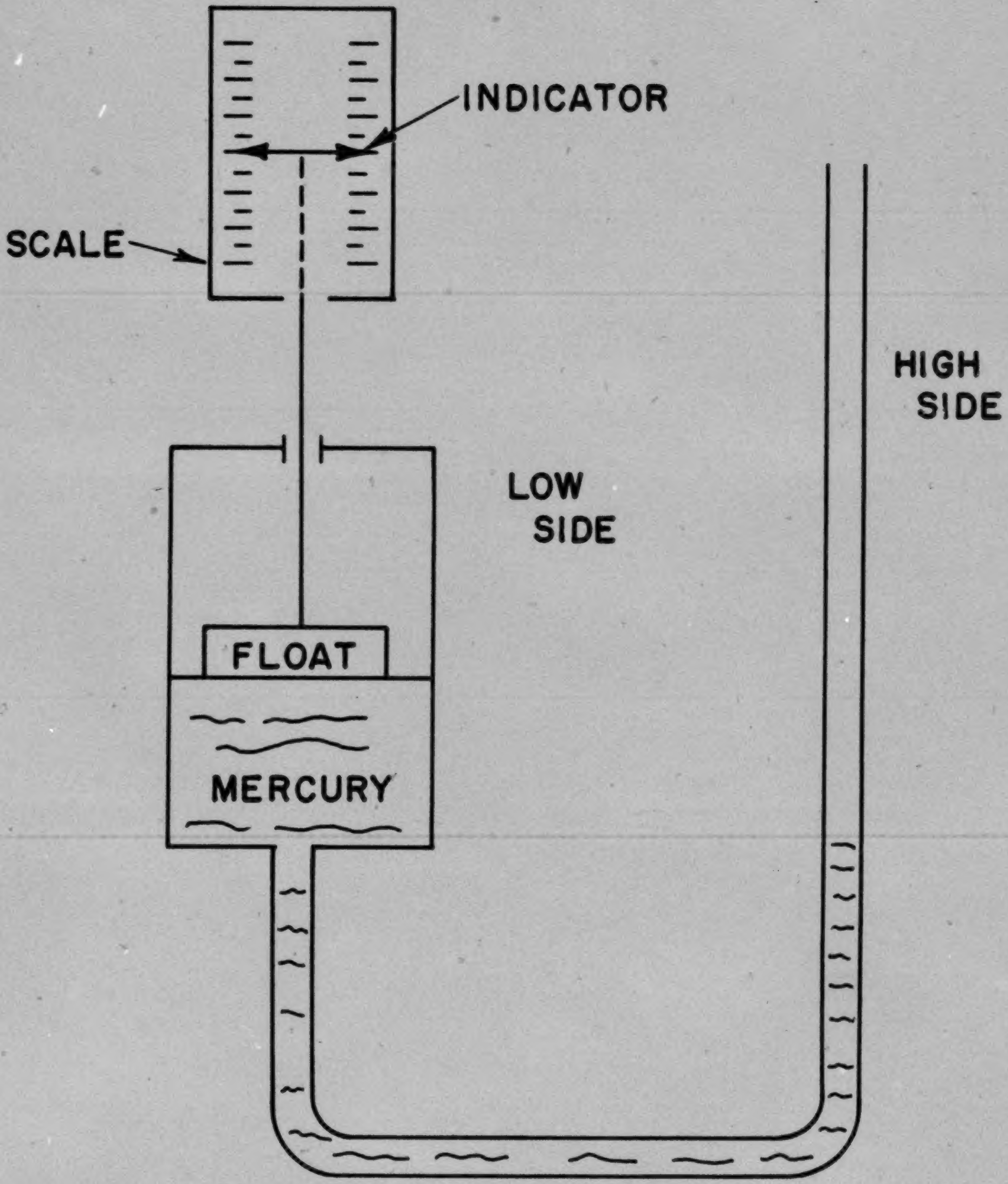
All of these factors have to be taken into consideration when selecting the proper flow meter for a given application. The most important is the velocity because it determines the behavior of a fluid. When the velocity is slow, the fluid flows in layers; and it is said to be laminar. The faster moving layers are nearer the center; and the slower layers are on the outer edges. With an increase in velocity, the flow is more turbulent. The layers tend to disappear, and the velocity across the stream becomes uniform.

By placing a restriction across this flow, we obtain a differential pressure which is sufficient to send to a mechanical or electrical meter. The meter then converts the differential of pressure into a rate of flow and sends it to a recorder in most cases.

References: *Instrumentation*
Elementary Steam Power Engineering
Combustion Engineering

Assignment:

1. What is the simplest piepline restriction for flow metering?
2. The most accurate method of flow metering is by using what kind of restriction in the pipeline?
3. Define the following terms:
   a. Pressure
   b. Density
   c. Viscosity
   d. Velocity
4. What is meant by the terms:
   a. Laminar
   b. Turbulent
5. What units of measurement are steam flowmeters calibrated to read?
6. Explain in your own words how a differential pressure flow meter functions?
7. Where could flowmeters of this type be used in a steam generating plant?


INDICATOR
SCALE
HIGH SIDE
LOW SIDE
FLOAT
MERCURY

DIFFERENTIAL PRESSURE METER

11-A-1

Objectives:

1. Be able to explain how a positive displacement flowmeter functions.
2. Be able to describe the basic construction of a positive displacement flowmeter.
3. Be able to explain how a variable area flowmeter functions.
4. Be able to describe the basic construction of a variable area flowmeter.

Information: Positive displacement meters measure a fixed amount of a fluid; and then they discharge it completely. This is very much like the positive displacement pumps that we discussed in a previous lesson. One type of positive displacement meter employs a wobble plate that rotates while emptying and filling a compartment as the fluid flows through it. The wobble plate connects at the top to a series of gears and indicates rate of flow.

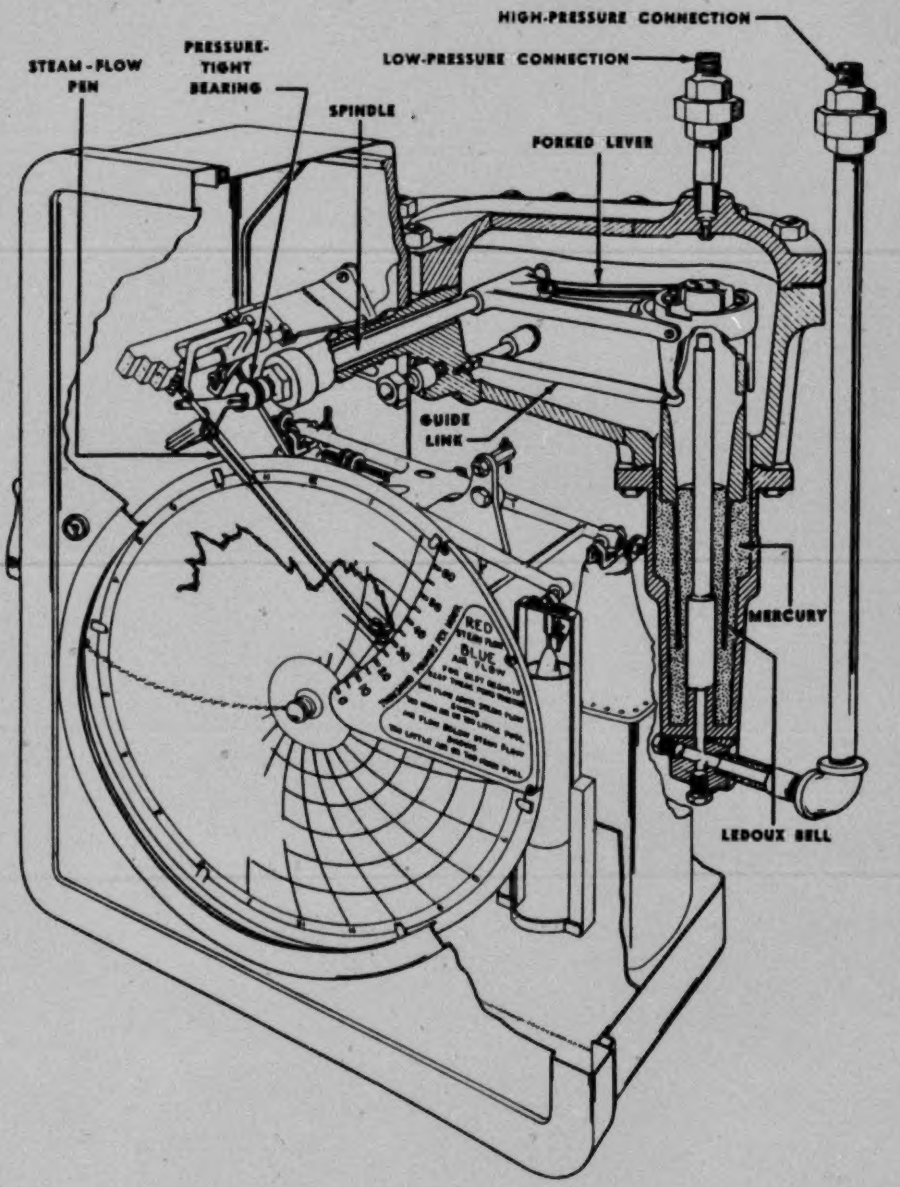
There are two types of variable area meters – the rotameter and the valve-type. With the rotameter, the area is varied by a float in a tapered tube. The movement of a self-positioning valve varies the area. In both of these variable area meters, the pressure differential across the restricting device is constant. The restricting device is across the float in the rotameter. As the float rises the area around it increases, but the difference in pressure across it remains the same. This is also true for the valve type, but the restricting device is a piston instead of a float.

References:

Instrumentation
Elementary Steam Power Engineering
Combustion Engineering

Assignment:

1. List the two types of variable area meters.
2. How does each type of meter function?
3. How does the positive displacement meter work?
4. Name some of the fluids that can be used with these meters.
5. Explain why the pressure differential is constant across the float in a rotameter even when the flow changes.



HIGH-PRESSURE CONNECTION
LOW-PRESSURE CONNECTION
STEAM-FLOW PEN
PRESSURE-TIGHT BEARING
SPINDLE
FORKED LEVER
GUIDE LINK
MERCURY
LEDOUX BELL
RED
STEAM FLOW
BLUE
AIR FLOW

11-A-2

Objectives:

1. Be able to explain how a draft gage functions.
2. Be able to describe how draft gages are constructed.

Information: The difference in pressure between two points is known as draft. The pressure, although quite small, may be measured above or below the atmosphere. Draft is necessary for the combustion process in a boiler to take place. Air is supplied to the furnace, and the products of combustion are removed by passing through the boiler and up the chimney or stack. Draft gages are of the manometer or diaphragm types.

The manometer type draft gage consists of a simple U-tube that measures the difference in height of a liquid such as water. Instead of the U-tube, an inclined tube is sometimes used for small pressures and for a greater degree of accuracy.

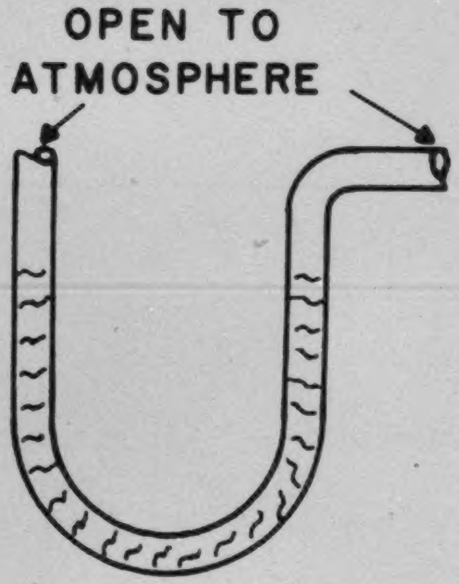
The diaphragm draft gage consists of a diaphragm, linkage, and pointer with a scale calibrated in tenths of an inch of water pressure. It operates in the following manner. The top and bottom of the diaphragm are connected to the two points to be measured. Any difference in pressure between the two points will cause the diaphragm to move. The diaphragm is attached to linkage that will cause movement of the pointer to indicate a reading on the scale.

References:

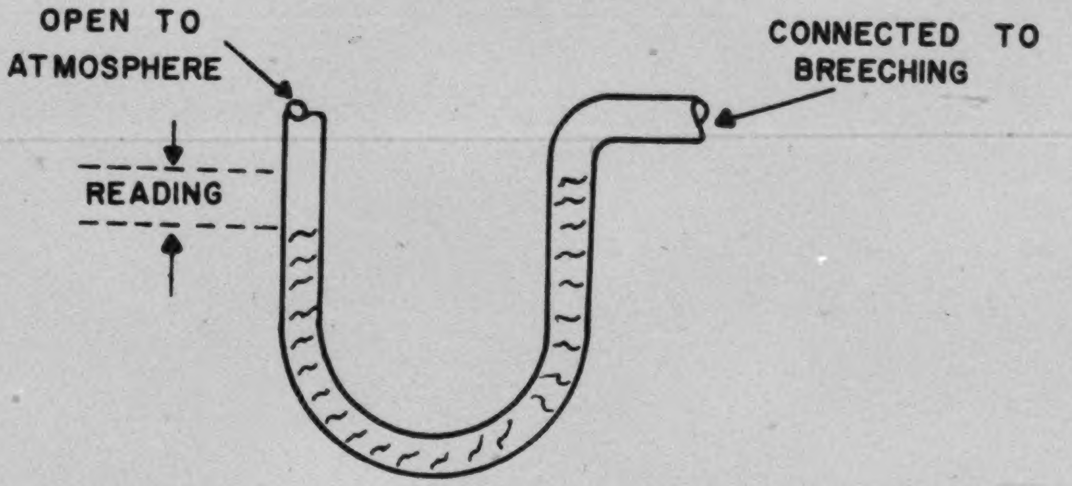
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. List the types of draft gages in use today.
2. How are they constructed?
3. How do they operate?
4. What points on a boiler would be connected to a draft gage?

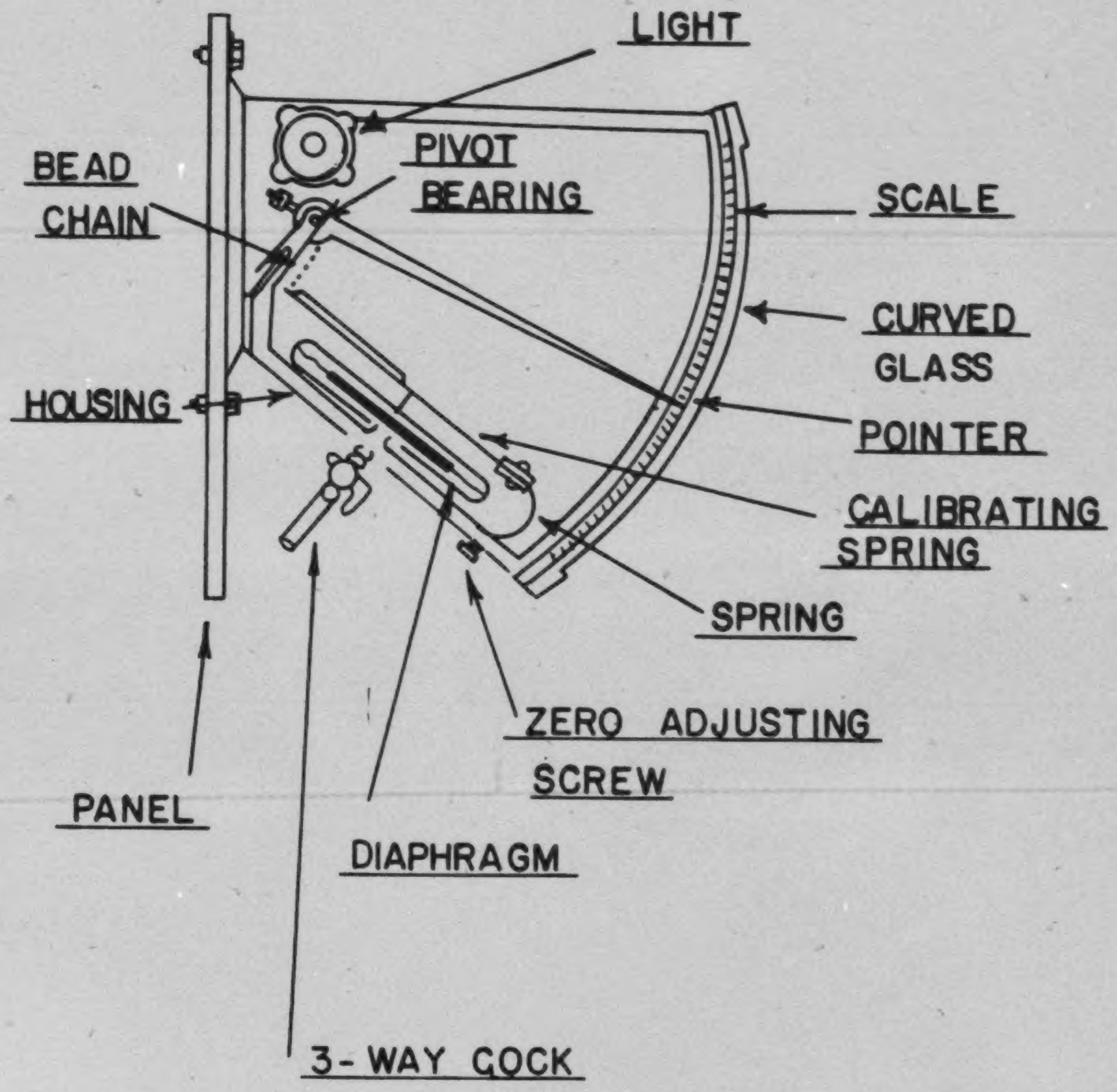

OPEN TO ATMOSPHERE

MANOMETER MEASURES DRAFT WITH U-TUBE TYPE GAGE. BOTH LEGS ARE EQUAL LEVEL AT ATMOSPHERIC PRESSURE.


OPEN TO ATMOSPHERE
CONNECTED TO BREECHING
READING

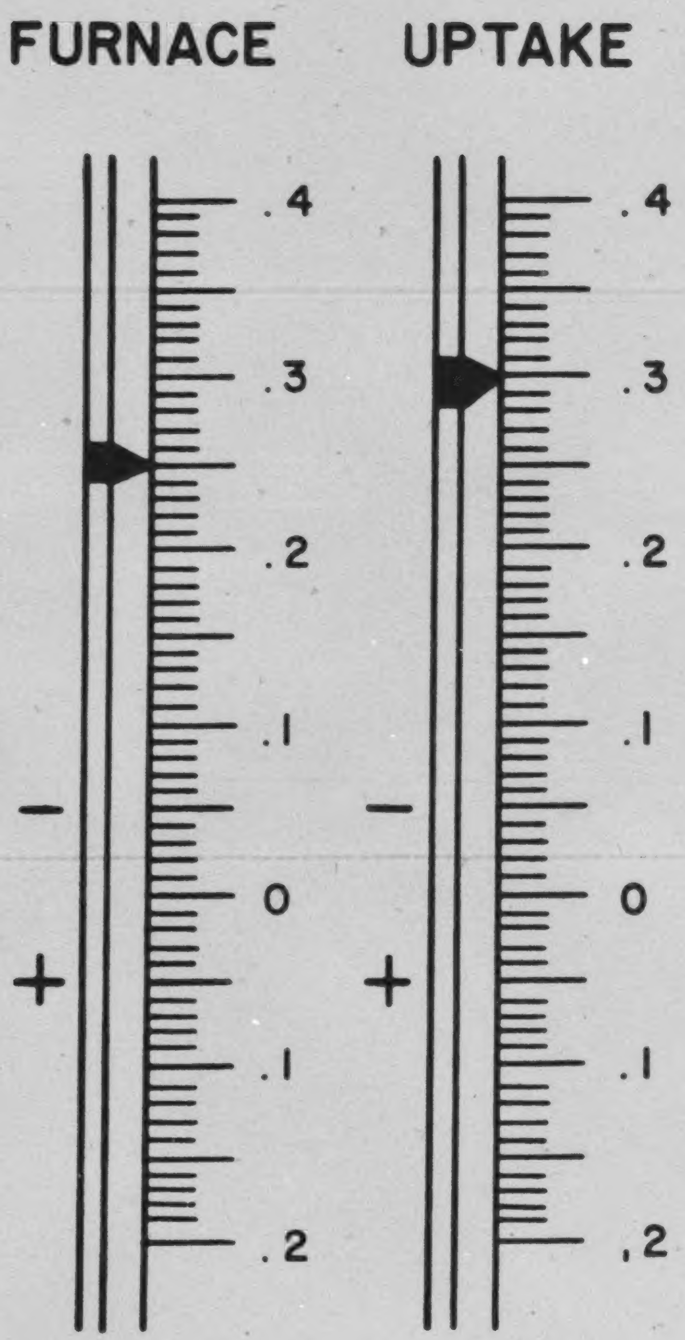
DRAFT GAGE CONNECTED TO BREECHING SHOWING NEGATIVE READING. WATER RISES IN LEG CONNECTED TO BREECHING.

11-B-1-1


LIGHT
PIVOT BEARING
BEAD CHAIN
SCALE
CURVED GLASS
HOUSING
POINTER
CALIBRATING SPRING
SPRING
ZERO ADJUSTING SCREW
PANEL
DIAPHRAGM
3-WAY COCK

DIAPHRAGM PRESSURE GAUGE

11-B-1-2


FURNACE
UPTAKE
.4
.3
.2
.1
−
0
+
.1
.2
.4
.3
.2
.1
−
0
+
.1
.2

II-B-1-3

Objective: 1. Be able to convert inches of draft to pounds per square inch.

Information: From our previous lessons, we know that for every vertical foot of water a pressure of .433 pounds per square inch is exerted on the base. If we divide .433 pounds per square inch by 12, the result will be a new factor of .0361 p.s.i. for each inch of water column.

$$\frac{\text{Pounds per Square Inch}}{\text{Inch of Water}} = \frac{.433}{12} = \frac{.0361\ \text{p.s.i.}}{\text{Inch of Water}}$$

When you convert inches of draft into equivalent p.s.i., you proceed as per examples below:

1. Convert 3" of force draft into p.s.i.:

p.s.i. = No. of Inches X .0361
p.s.i. = 3 X .0361
p.s.i. = .1083

2. Convert .15" of furnace draft into p.s.i.:

p.s.i. = No. of Inches X .0361
p.s.i. = .15 X .0361
p.s.i. = .005415

Assignment:

1. How many pounds per square inch pressure is there at the base of a 1-foot water column?
2. Convert 6" of water to p.s.i.
3. Convert 2.5" of water to p.s.i.
4. How much pressure would be needed to raise a draft gage 1.8 inches?

Objectives:

1. Be able to explain how thermocouples work.
2. Be able to list the uses of thermocouples in steam generating plants.

Information: You may recall that the thermocouple consists of two wires of dissimilar metals of different electrical conductivity. They are welded together at one end and sealed in a porcelain tube. Wires connected to this tube may then be connected to a galvanometer, or to some form of amplifying device, in a control circuit. The amount of electromotive force depends on the difference between the temperature of the two junctions and the type of materials being used for conductors. The welded wires are then exposed to heat. As heat is picked up, a very small electric voltage is induced. This voltage is proportional to the difference in temperatures between the two junctions. This current flows through the circuit and moves the indicator on the galvanometer. The dial of the galvanometer has been calibrated to read degrees. If the thermocouple is used in a control circuit, the current flow is sent to an amplifier which would send out a stronger signal that can then be used.

The advantages of using a thermocouple to measure temperature are:

1. Accurate readings.
2. Good over wide range with rapid readings.
3. Fairly low cost.
4. Can be used for many applications.
5. Can be centrally located taking reading from many remote locations in the plant.

In a steam generating plant, some of the temperatures that thermocouples are used to measure are:

Superheated steam
Desuperheated steam
Feed water entering boiler
Condensate returns
Flue gas entering stack
Condenser water on and off
Combustion air temperature

It will depend upon the type and size of the steam generating plant as to how many thermocouples are needed.

Recorders are used in conjunction with thermocouples to give a continuous reading of the temperatures at various points. The data taken from the recorders is very useful, when it is necessary to determine plant performance. Instant readings are helpful in locating problems in the system before they become serious.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. Explain how a thermocouple works.
2. List the advantages of using a thermocouple.
3. Where would thermocouples be used in a modern steam plant?
4. Why are recorders used in conjunction with thermocouples?
5. What is the value of having a record of temperatures when operating a steam plant?

Objectives:

1. Be able to explain the purpose of recorders.
2. Be able to explain how to use the data from a recorder.

Information: Recorders are that part of instrumentation dealing with the measuring of a substance. The recorder can be linear or circular and large or small. It may have strip charts or circular charts. It may be mechanical, electrical, or a combination of both. Some recording instruments are limited to one measured variable; others accommodate many records. Recorders are used throughout the modern world. The development and progress of industry has relied on the development of instrumentation. The use of recorders can be found throughout industry to measure flow, pressure, temperature, level, humidity, and electricity. Some examples of the use of recorders in modern steam generating plants are to measure the (1) flow, (2) pressure, (3) temperature and (4) level of water, steam, air and gas.

Recorders indicate operating conditions continuously, therefore the operator of steam plant equipment has a thorough knowledge of how the plant is functioning at all times. It is also possible to determine plant performance and efficiency from the data taken from recorders. This is important in our modern world with the shortage and high cost of fuels.

References:

Instrumentation
Combustion Engineering
Steam Plant Operation

Assignment:

1. Indicating instruments have one feature in common – a scale calibrated in units of the measured variable. What does this mean?
2. In your own words, describe what a recording instrument does and tell why you think this is important.
3. Give some examples of recording devices, and tell what they would be used to record.
4. Why has industry become so dependent on recorders?
5. Explain why you think you could operate a steam generating plant more efficiently with recorders than without.

Smoke Indicator — Assignment 11-E-1

Objectives:

1. Be able to explain the purpose of a smoke indicating device.
2. Be able to describe how the smoke indicating device works.

Information: There has never been any way to measure the amount of smoke given off by a furnace. It has usually been determined by visual inspection of the stack. Visual inspection is not always the most accurate method because it is affected by the condition of the atmosphere (bright, cloudy, raining, etc.), the background appearance, and by the person making the observation. A comparitive chart known as the Ringelmann chart is used to determine smoke density. It is made up of 6 charts and shows readings from 0 to 100% smoke density. The charts are used in the following manner. They are placed 50 feet from the observer who then compares the smoke from stack with the charts. From this observation he can then determine smoke density from the stack by selecting the chart that compares with the stack.

Another method of evaluating the density of combustion gases is by measuring the amount of light that is cut off as it passes through them. The instrument that is used for this is known as a smoke gage or smoke indicator. It is comprised of the following parts:

1. Light source – usually a standard 100 or 150 watt light bulb with a reflector.
2. Photo electric pick-up unit – picks up radiation from the light source.
3. Indicator and/or recorder – to indicate and record smoke density.

The reading on the gage and recorder will depend upon the density of the combustion gases. If the gases across the light source to the photo electric cell are clear, the readings will be toward 0. On the other hand if the gases are heavy with smoke, readings will move toward the 100 mark. This type of instrument used in conjunction with a strip chart recorder is very helpful to power plant personnel in controlling the smoke from boiler furnaces.

Reference: *Elementary Steam Power Engineering*

Assignment:

1. Why do we have to limit the amount of smoke passing into the atmosphere?
2. What is a Ringelmann chart?
3. How would it be used?
4. Explain how the photo electric cell type of smoke indicator works.
5. What type do we have in our boilerroom, and how does it operate?

Boiler Water Chemistry — Assignment 12-A-1

Objectives:

1. Be able to explain the fundamentals of the chemistry of boiler water.
2. Be able to define the basic terminology used in boiler water chemistry.

Information: The sources of water found in nature are never in the pure state. Rain water picks up gases and particles from the air as it falls. Surface waters can contain solids, gases, and possible pollution from industrial wastes. Ground water from wells and springs tends to dissolve solids as it passes through the ground; these solids show up as carbonates of magnesium and calcium. Drinking water supply stations, private or municipal, do not remove dissolved solids from the water; they filter and chlorinate to make the water good for drinking. It has been found necessary to condition boiler water from any source. The steam boiler must be protected from the following conditions that are a direct result of boiler water condition.

1. Caustic embrittlement – caused by high alkaline solution
2. Scale – deposits of calcium and magnesium carbonates on the heating surfaces
3. Corrosion – pitting and channeling of metal. Caused by gases in the water.
4. Carryover – carrying over of water into steam lines. Caused by high alkalinity, dissolved solids, and sludge.

We can readily see that we can protect a boiler if we can prevent these conditions from happening. With caustic embrittlement, we must maintain the proper alkalinity at all times. Scale can be prevented by rendering the carbonates of calcium and magnesium into non-adhering sludge; removing oxygen (O_2) and carbon dioxide (CO_2) from the water stops corrosion. Proper alkalinity, dissolved solids, sludge, and surface of water free of floating material (such as oil) prevents carryover.

References:

Steam Plant Operation
Practical Power Service Library
Elementary Steam Power Engineering

Assignment:

1. What are the possible sources of water for a steam boiler?
2. How does each source compare for purity?
3. Which source would be the best for a steam boiler?
4. What conditions in a boiler are caused by impurities within the water?
5. Describe each condition in detail.

Dangers of Neglecting Boiler Water Treatment — Assignment 12-A-2

Objectives:

1. Be able to describe the danger of neglecting proper boiler water conditioning.

Information: From the last lesson, we know that improper treatment of boiler water will eventually give a problem of caustic embrittlement, scale formation, corrosion, or carryover. Now, let's examine each of these conditions and see if any danger exists to the boiler or to the personnel operating it.

Caustic embrittlement can cause cracking of the metal along the seams and at the ends of tubes. This could cause taking the boiler out of service for repairs. If the condition was ignored, there is a possible danger of complete boiler failure and injury to operating personnel.

Scale formation on tubes and boiler drums is a direct cause of boiler failure due to overheating of the metal. Scale acts as an insulating material between the combustion side of the boiler and the water. Overheating of the boiler metal causes leaks, cracks, bags (large blister), distortion of tubes and tube sheets, and also complete failure.

Corrosion or pitting weakens the boiler structurally by thinning the boiler plates and tubes. If left unchecked, it will lead to complete failure.

Carryover is a very dangerous condition because of water hammer in the steam lines. It can lead to steam header or line rupture, which is highly dangerous to operating personnel and to plant equipment.

Boiler inspectors are very conscious of the above conditions. During their annual inspection of a steam boiler, they carefully inspect for any of the problems mentioned. Then they notify the Mechanical Inspection Bureau of any unusual conditions. The Mechanical Inspection Bureau can, when warranted, lower the pressure, force repairs, or condemn a boiler as being unsafe.

References:

A.S.M.E. Code
Steam Plant Operation
Elementary Steam Power Engineering
Practical Power Service Library

Assignment:

1. List the dangers of:
   a. carryover
   b. corrosion
   c. caustic embrittlement
   d. scale formation
2. Could the above conditions have been avoided? Explain.

Objective:

1. Be able to explain how boiler water is chemically treated to maintain a proper balance of chemicals.

Information: In a steam boiler we must treat the water to prevent scale formation on tubes and heating surfaces, corrosion of the shell and tubes, caustic embrittlement at seams, and carryover of boiler water into superheaters and headers. Let's analyze each of these conditions and how they can be controlled. Scale is formed when calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) are deposited on hot metal surfaces to form a hard, brittle scale. It can be controlled by caustic soda (NaOH) which would react as follows:ring light glows when an error occurs due to

$$CaCO_3 + 2NaOH \rightarrow Na_2CO_3 + Ca(OH)_2$$

$$MgCO_3 + 2NaOH \rightarrow Na_2CO_3 + Mg(OH)_2$$

Now instead of having a scale-forming substance, we have a non-adhering sludge. To complete this change, a compound of phosphate such as sodium phosphate ($Na\ PO_3$) is introduced; this changes the calcium and magnesium into calcium phosphate and magnesium phosphate which are non-adhering sludges. Corrosion is caused by oxygen and carbon dioxide. They are best removed outside of the boiler by heating the feed water before it enters the boiler. To be sure that there is not any corrosion taking place, a sodium sulphite (Na_2SO_3) is added to remove any oxygen present. The oxygen will change the sulfite into a sulphate (Na_2SO_4). Caustic embrittlement can be prevented by not allowing leaks along the seams or at rivets. Boiler water must be maintained at the proper alkalinity level; add sufficient caustic soda to prevent scale. Carryover is caused by high total solids, high alkalinity, and scum or other impurities on the surface of the water. This condition can be prevented by:

1. Keeping a low alkalinity.
2. Reducing total solids by blowing-down boiler.
3. Removing impurities from the surface of the water through a surface blowdown line.

From the above information, we can see that we have to control boiler water to maintain:

1. Correct alkalinity
2. Correct total solids
3. Correct sulphite
4. Correct phosphates

References: *Practical Power Service Library*
Steam Plant Operation
Elementary Steam Power Engineering

Assignment:

1. How is scale prevented from forming in a steam boiler?
2. How are the total solids in a boiler formed?
3. What reaction takes place within a steam boiler when we add sulphite?
4. How can carryover be controlled?
5. What has to be done to control or prevent caustic embrittlement?

$$\boxed{\mathrm{Ca\,CO_3}} + \boxed{\mathrm{Na\,OH}}\,\boxed{\mathrm{Na\,OH}} \longrightarrow \boxed{\mathrm{Na_2\ CO_3}} + \boxed{\mathrm{Ca\,(OH)_2}}$$

$$\boxed{\mathrm{Mg\,CO_3}} + \boxed{\mathrm{Na\,OH}}\,\boxed{\mathrm{Na\,OH}} \longrightarrow \boxed{\mathrm{Na_2\ CO_3}} + \boxed{\mathrm{Mg\,(OH)_2}}$$

$$\boxed{\mathrm{Na\,PO_3}} + \boxed{\mathrm{Ca\,CO_3}} \longrightarrow \boxed{\mathrm{Na_2\ CO_3}} + \boxed{\mathrm{Ca\ PO_3}}$$

NOTE: THIS REACTION IS MORE COMPLEX THAN THIS EQUATION SHOWS AND IS NOT COMPLETELY BALANCED.

$$2\,\boxed{\mathrm{Na_2\,SO_3}} + \boxed{\mathrm{O_2}} \longrightarrow 2\,\boxed{\mathrm{Na_2\ SO_4}}$$

BOILER WATER TREATMENT REACTIONS

Objective:

1. Be able to describe the basic types of systems that are used for external treatment of boiler water.

Information: From our previous lesson, we know that boiler water has to be treated to make it suitable for use in steam boilers. This can be done internally, externally, or in some cases by using a combination of both methods. The external methods that are in general use are the cold lime-soda process, the hot lime-soda process, and the ion-exchange or zeolite process.

The cold lime-soda method is carried out at room temperature; it softens the water by forming sludge from the calcium and magnesium compounds. The sludge is removed and the water is passed through a filter for clarity. This is a batch type of process that requires about 6 hours to complete.

The hot lime-soda method is carried out at a temperature above 212°F.; it uses exhaust or live steam to maintain this high temperature. It performs the same function as the cold soda-lime process softening the water and removing sludge and some silica. The big difference is that it can do this continually as long as soda is added and sludge is removed.

The ion exchange or zeolite process is carried on at room temperature, and it softens the water by changing the calcium and magnesium carbonates into sodium carbonates, calcium zeolite, and magnesium zeolite. This is done by ion exchange taking place in the solution. Once the zeolite holds as much calcium and magnesium as possible, the unit must be regenerated by passing sodium chloride (common salt) over the zeolite. The sodium removes the calcium and magnesium from the zeolite and washes it out. It is then again ready for service.

Even when external treatment of boiler water is done, it is still necessary to carry a residual amount of chemicals within the steam boiler for protection.

References:

Water Conditioning Handbook
Steam Plant Operation
Practical Power Service Library

Assignment:

1. Name the different types of systems that are available for boiler water conditioning.
2. What does each one do to the water?
3. What advantages has one system over the others?
4. What undesirable impurities are taken out in these softeners?

Objectives:

1. Be able to explain how to maintain a proper level of chemicals in the boiler.
2. Be able to explain how to control the total solids in the boiler.

Information: By maintaining the correct amount of chemicals in a boiler, we can prevent damage or destruction of the unit. The items that have to be controlled are:

1. Alkalinity – this can be done by testing the pH value of the water. If the reading is lower, than specified, caustic soda (Na OH) has to be added.
2. Phosphates – a comparison test is used with an indicator to show the residual present in the water. If low, a phosphate solution is added.
3. Sulphite – determination is done to maintain a residual, to scavenge for oxygen. If low, sodium sulphite is added.
4. Total solids – must be kept within certain limits. A conductivity meter can determine the total solids. If high, the bottom blowdown must be used to reduce solids. Some plants use a continuous blowdown for control.
5. Surface impurities – have to be removed as they accumulate. This is done with a surface blowoff valve.

In most steam generating plants, chemicals are added continuously in a diluted form. A daily analysis determines whether the amount has to be increased or decreased. Continuous blowdown is used also in preference to a bottom blowdown. These methods maintain much more consistancy in the level of chemicals within the boiler water.

References: *Steam Plant Operation*
Elementary Steam Power Engineering

Assignment:

1. What tests are needed when analyzing boiler water?
2. How do you maintain the proper level of chemicals in a boiler?
3. What types of chemicals are added?
4. How are the total solids controlled (both methods)?
5. What are the advantages of a continuous system of treatment and blowdown over the batch system?

Blowdown Tank — Assignment 12-C-2

Objectives:

1. Be able to explain the purpose of a blowdown tank.
2. Be able to locate a blowdown tank in the school plant.

Information: All steam boilers are equipped with a bottom blowdown line, which we have discussed in a previous lesson. Can you recall the four uses of a bottom blowdown line? No! Well they were:

1. To remove sludge and sediment.
2. To drain boiler
3. To lower water level
4. To control chemicals

The blowdown line cannot be connected directly to a sewer system because of the pressures and temperatures involved. If connected, it would be a direct violation of the New Jersey Pressure Vessel Code.

In order to prevent hot water and steam from entering the sewer system, a blowdown or flash tank must be used between the blowdown line and the sewer. The blowdown lines are connected to this tank as shown in Figure 12-C-2-1 and Figure 12-C-2-2. The hot water and steam enters at the top of the tank. The flash steam leaves through the vent and the hot water stays in the tank. As the level in the tank rises, cooler water from the bottom of the tank overflows into the sewer. After blowing down a boiler, the water remains in the blowdown tank to cool until another boiler is blown down. A siphon breaker is installed to prevent possible siphoning of the water in the tank.

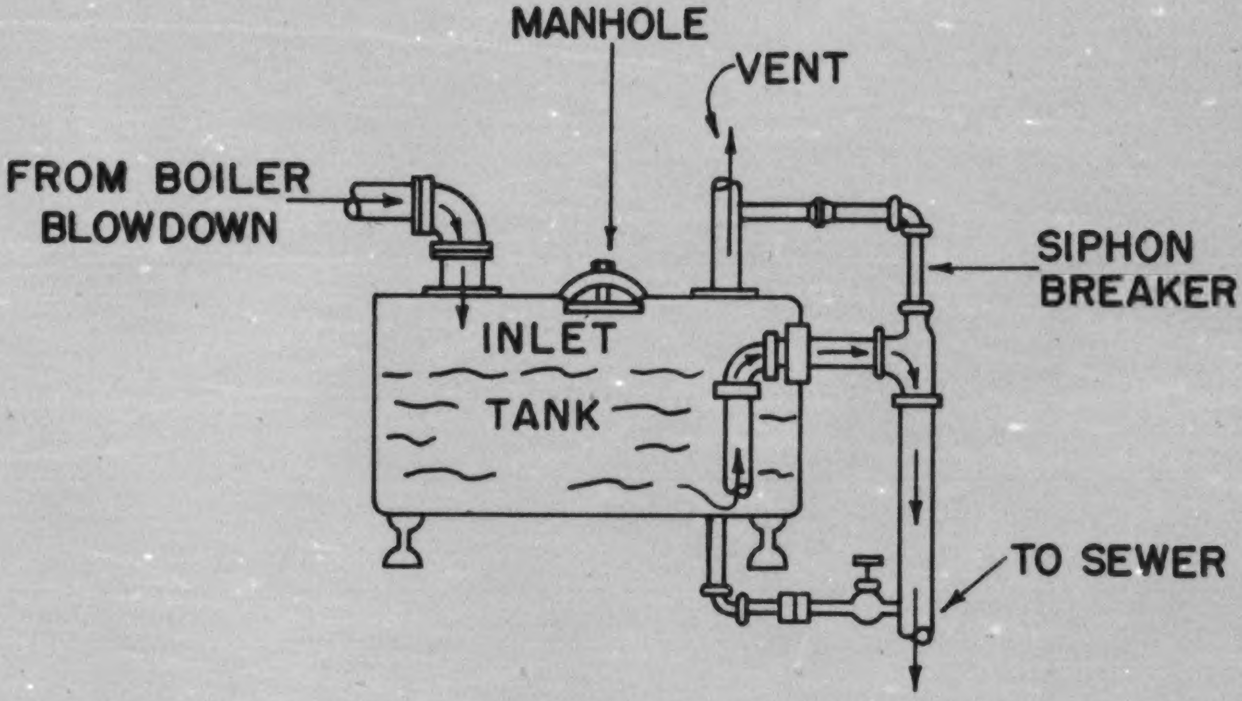
References:

Steam Plant Operation
Boiler Room Questions and Answers

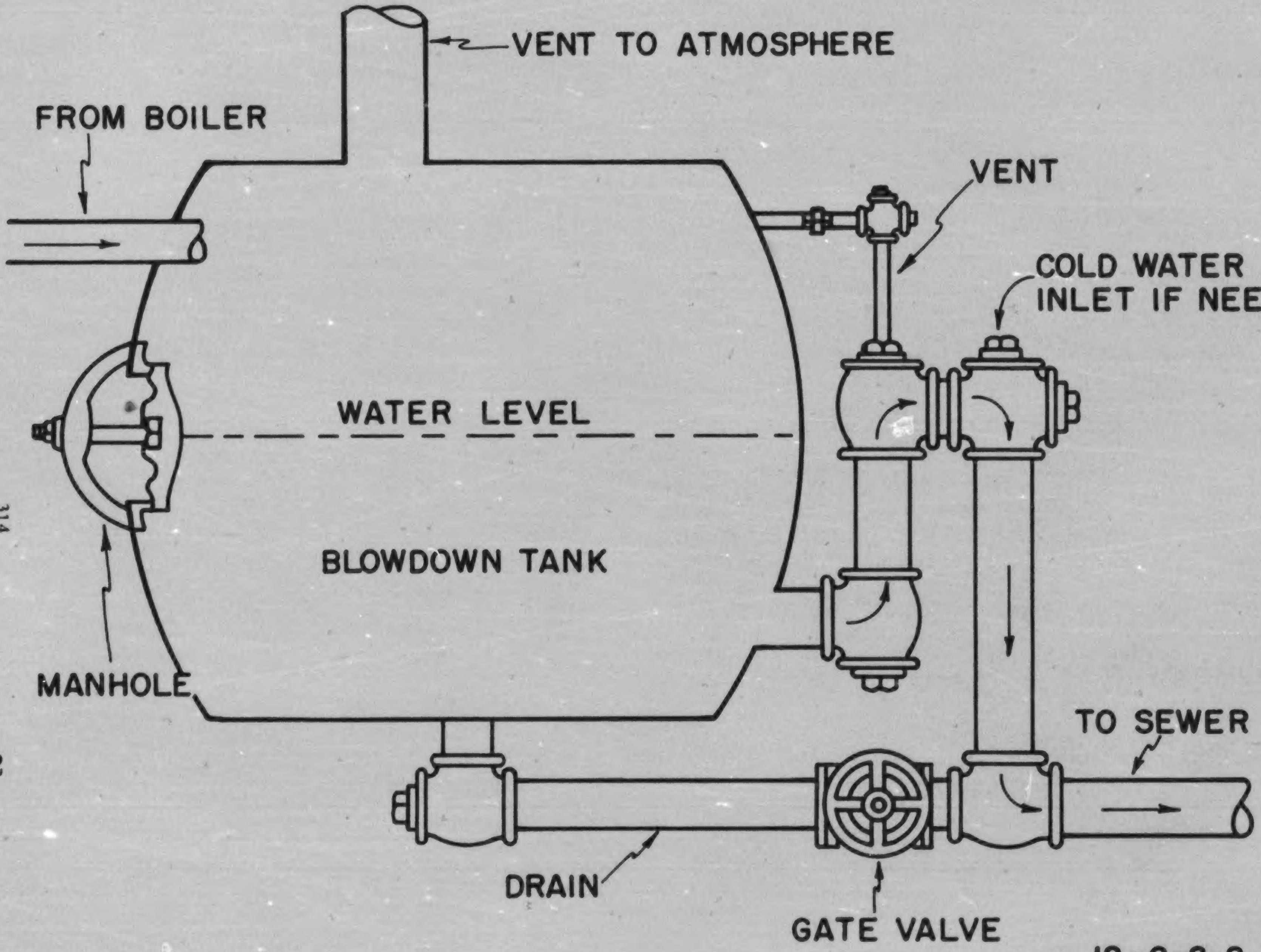
Assignment:

1. Why is it necessary to use a blowoff, blowdown, or flash tank?
2. Why is the blowdown tank vented to the atmosphere?
3. Why is the outlet line from the blowdown tank vented?
4. What is the purpose of a drain valve on the blowdown tank?
5. Why is the outlet connection of the blowdown tank under water?
6. What other purpose does the blowdown tank serve when the boiler is off the line?

C


MANHOLE
VENT
FROM BOILER BLOWDOWN
SIPHON BREAKER
INLET
TANK
TO SEWER

12-C-2-1


VENT TO ATMOSPHERE
FROM BOILER
VENT
COLD WATER INLET IF NEEDED
WATER LEVEL
BLOWDOWN TANK
MANHOLE
TO SEWER
DRAIN
GATE VALVE

12-C-2-2

Objectives:

1. Be able to explain the terminology and the uses of compressed air.
2. Be able to explain the principles of operation of a compressed air system.
3. Be able to explain the A.S.M.E. requirements for a compressed air system.

Information: The use of compressed air in industry is wide and varied. This is partly due to its being easy to distribute throughout a plant. It is used for control air at pressures of 1 to 30 pounds and for air driven tools at 50 to 80 pounds. It is also used for cleaning and sandblasting operations and spray painting.

Compressors fall into two broad categories:

1. Reciprocating
2. Centrifugal

The reciprocating compressor must be fitted with suction and discharge valves, a cylinder with a piston, and rings. This creates a problem with lubrication because of metal-to-metal contact. The oil used in air compressors must be special to prevent explosions. In compressing air, large amounts of heat build up; and the presence of oil could be hazardous. The principle of operation of a diesel engine is the compression of air building up high heat; the oil is injected into the cylinder and ignited.

The centrifugal compressor does not pose this problem because there are no valves or metal-to-metal contact. In dealing with compressed air, we must add some new terminology to our vocabulary.

1. Free air – we live in free air, (Maybe not for long – it might cost us like water). It is the air available at the suction side of the compressor. The conditions of this free air will change with temperature and atmospheric pressure changes.
2. Capacity – refers to the amount of air actually delivered by a compressor rated in cubic feet per minute.
3. Piston displacement – rated in cubic feet. It is found by multiplying the piston area in square feet times the piston stroke in feet.

$$V_c = A_c \times L_s$$

where:

V_c = Volume of cylinder in cu. ft.
A_c = Area of cylinder in sq. ft.
L_s = Length of stroke in feet

For example, a compressor has a piston 3 feet in diameter with a 2-foot stroke. Its piston displacement would be:

$$\begin{aligned} V_c &= A_c \times L_s \\ &= 3 \times 3 \times .7854 \times 2 \\ &= 7.0686 \times 2 \\ &= 14.1372 \text{ cubic feet} \end{aligned}$$

4. Displacement per minute is rated in cubic feet per minute; and it is arrived at by multiplying the piston displacement in cubic feet times the revolutions per minute.

   Example: The above compressor is turning 100 r.p.m. It is a single acting compressor. What is its displacement per minute?

$$V/\text{Min.} = A_c \times L_s \times N$$

where:

V = final volume in cubic feet
A_c = area of cylinder in square feet
L_s = length of stroke in feet
N = number of discharge strokes per minute

When figuring piston displacement per cubic foot per minute in a multistage compressor, only the low-pressure cylinder is used. This is because it will determine the amount of air passing to the other cylinders.

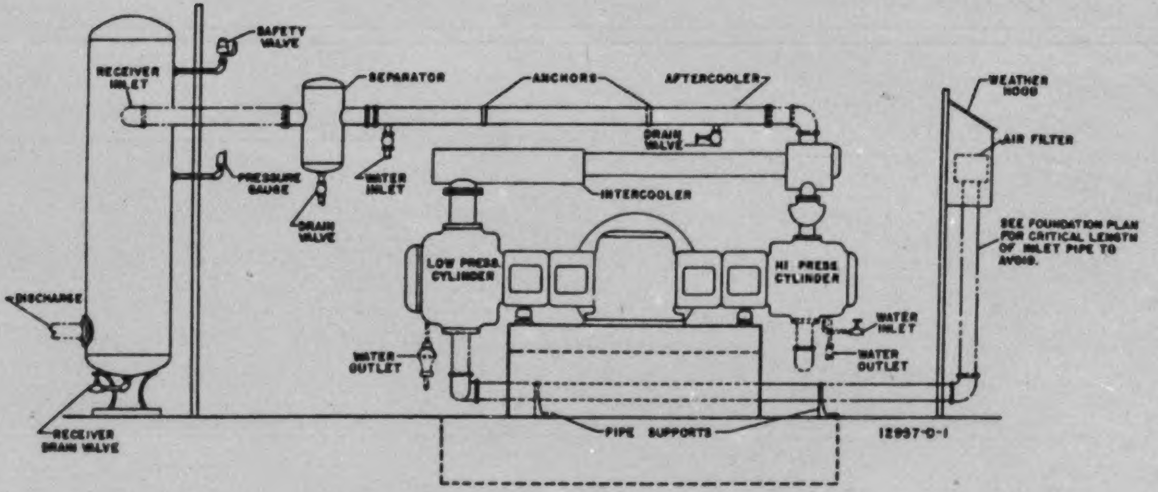
$$\begin{aligned} V/\text{Min} &= A_c \times L_s \times N \\ &= 3 \times 3 \times .785 \times 2 \times 100 \\ &= 7.0686 \times 2 \times 100 \\ &= 14.1372 \times 100 \\ &= 1413.72 \text{ cu ft./min.} \end{aligned}$$

Figure 13-A-1-1 shows a horizontal two-stage air compressor, and Figure 13-A-1-2 shows a two-stage combination horizontal-vertical compressor. The principle of operation of an air compressor is the taking of free air, compressing it to reduce its volume, and to increase its pressure. When large volumes of air are needed, multistage air compressors are used. They are equipped with water-cooled cylinder, intercoolers and after-coolers to remove the heat of compression and deliver cool air to the plant. Air compressors and receivers come under the A.S.M.E: Unfired Pressure Vessel Code, Section VIII. This code insures that all material conform to standards of safety. It stipulates thickness of metal used in piping and receivers, when safety valves must be located, and makes arrangements for inspection of equipment.

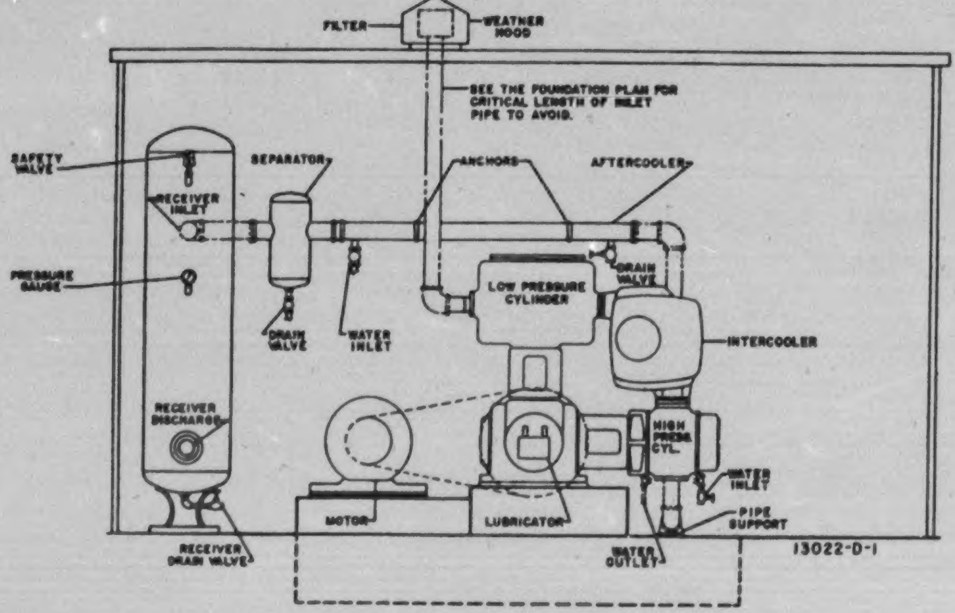
References: *Steam Air and Gas Power*
Elementary Heat Power

Assignment:

1. What part of the A.S.M.E. Code covers air compressors?
2. For what purposes is compressed air used in industry?
3. What are the two broad categories of air compressors?
4. Why does oil pose a special problem in the reciprocating type of compressor?
5. What is meant by free air?
6. In a multistage air compressor, how is heat removed between low- and high-pressure stages?
7. What is piston displacement? How is it found?


SAFETY VALVE
RECEIVER INLET
SEPARATOR
ANCHORS
AFTERCOOLER
WEATHER HOOD
DRAIN VALVE
AIR FILTER
PRESSURE GAUGE
WATER INLET
INTERCOOLER
DRAIN VALVE
SEE FOUNDATION PLAN FOR CRITICAL LENGTH OF INLET PIPE TO AVOID.
LOW PRESS. CYLINDER
HI PRESS CYLINDER
DISCHARGE
WATER INLET
WATER OUTLET
WATER OUTLET
RECEIVER DRAIN VALVE
PIPE SUPPORTS
12937-D-1

13-A-1-1


FILTER
WEATHER HOOD
SEE THE FOUNDATION PLAN FOR CRITICAL LENGTH OF INLET PIPE TO AVOID.
SAFETY VALVE
SEPARATOR
ANCHORS
AFTERCOOLER
RECEIVER INLET
PRESSURE GAUGE
DRAIN VALVE
LOW PRESSURE CYLINDER
DRAIN VALVE
WATER INLET
INTERCOOLER
RECEIVER DISCHARGE
HIGH PRESS. CYL.
WATER INLET
PIPE SUPPORT
MOTOR
LUBRICATOR
RECEIVER DRAIN VALVE
WATER OUTLET
13022-D-1

13-A-1-2

Objectives:

1. Be able to identify the parts of a compressed air system.
2. Be able to describe a compressed air cycle.

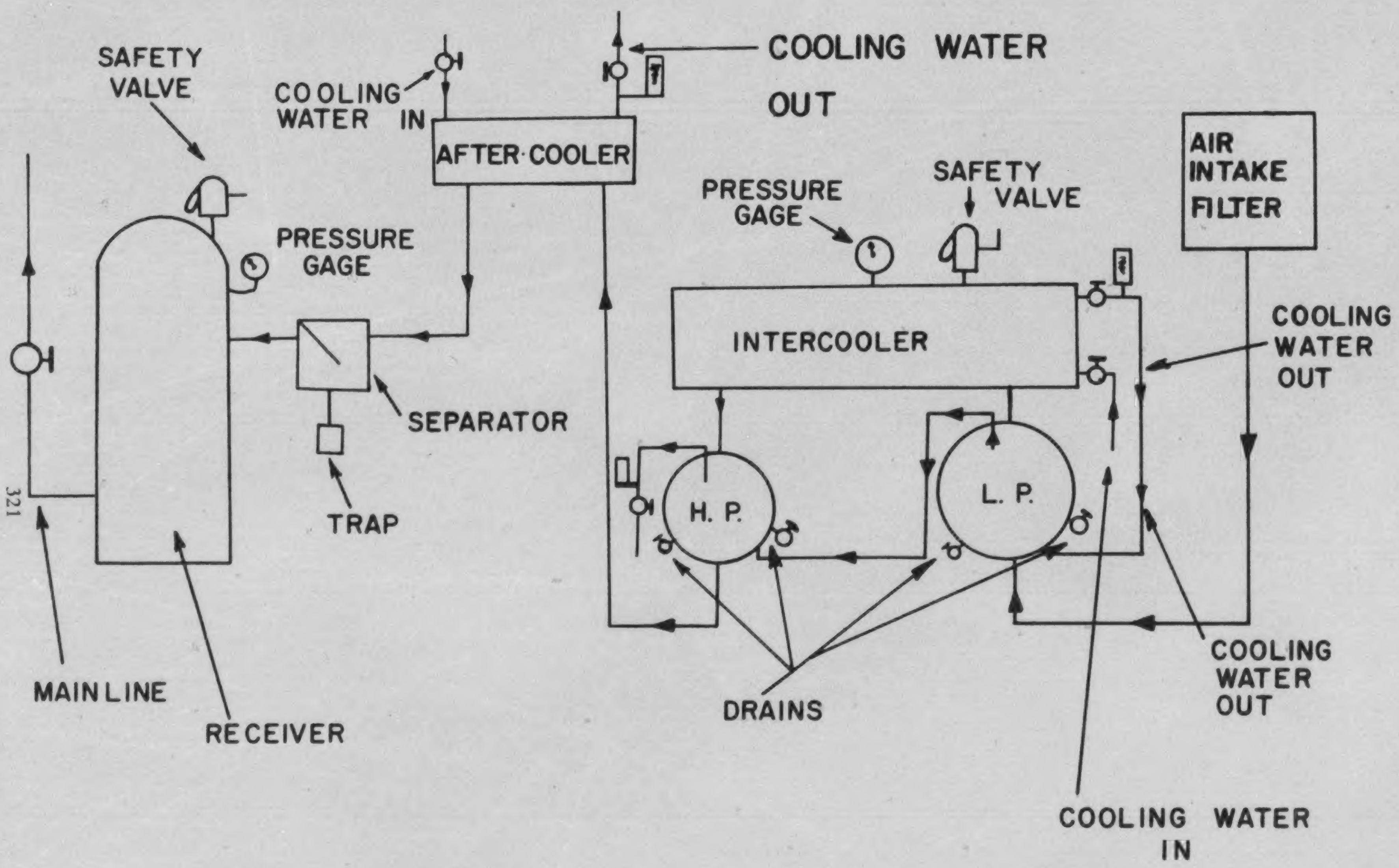
Information: In order to be familiar with how an air compression system works, we must first study the components and find out what they do. Using Figure 13-B-1-1, let's trace a cycle and see what each part of the system does. Free air is brought to the suction side of the low-pressure cylinder through a filter. Most large machines use an oil bath filter to remove the impurities in the air before it enters the cylinder. The air around us is good enough for us to breath, but it is not good enough for an air compressor. From the low-pressure cylinder, the compressed air passes through an intercooler. This intercooler removes the heat of compression. It should be mentioned here that both the low-pressure cylinder, the intercooler, and the high-pressure cylinder are water cooled. The intercooler is equipped with a pressure gage, which indicates the pressure of air leaving the low pressure (L.P.) side of the compressor. It has a safety valve to protect it against over pressure. There is also a thermometer on the cooling water outlet from the intercooler and a thermometer on the cooling water outlet from the high-pressure side of the compressor. These thermometers are needed so that the operator can adjust the flow of cooling water. The cooling water temperature leaving the intercooler and entering the L.P. cylinder is about 80°F. The temperature of cooling water leaving the H.P. cylinder is about 120°F. The air leaving the H.P. cylinder then passes through an aftercooler, through a separator where water and oil is trapped out, and to a receiver. The aftercooler removes the heat of compression from the H.P. cylinder. It too is water cooled, so that as much moisture as possible will be removed. The receiver is a storage point giving the plant a volume of air to draw from. It is protected from excessive pressure by a safety valve. The receiver must be constructed according to the A.S.M.E. Code and stamped as such. It is subject to internal inspection annually by a state or insurance inspector.

References: *Steam Air and Gas Power*
Elementary Heat Power

Assignment:

1. Why is the air filtered before entering the air compressor?
2. What limits the piston speed of the reciprocating compressor?
3. Why must the large synchronous motors driving air compressors be started under no-load conditions?

4. What is the purpose of an intercooler?
5. Why is a separator used in the system? Where is it located?
6. What purpose does the receiver serve? How is it protected from excessive pressure?
7. What is meant by a coded tank?
8. What is meant by a two-stage compressor?


SAFETY VALVE
COOLING WATER IN
AFTER·COOLER
COOLING WATER OUT
PRESSURE GAGE
SEPARATOR
TRAP
321
MAIN LINE
RECEIVER
PRESSURE GAGE
SAFETY VALVE
AIR INTAKE FILTER
INTERCOOLER
COOLING WATER OUT
H. P.
L. P.
DRAINS
COOLING WATER OUT
COOLING WATER IN

2-STAGE AIR COMPRESSOR

13-B-1-1

Objective: 1. Be able to calculate the capacity of an air compressor.

Information: The amount of air delivered by an air compressor will vary depending upon size, speed, pressure, and efficiency of the machine. The efficiency of an air compressor is approximately 75%. This can increase or decrease depending upon the final discharge pressure. An increase in discharge pressure causes a corresponding drop in the efficiency, and a lower pressure causes an increase in efficiency. If we assume that the efficiency of an air compressor is 100% and that the discharge air temperature is the same as the inlet air temperature, we can then use Boyle's Law for gases. The product of the initial pressure and volume will equal the product of the final pressure and volume.

$$\text{Pressure}_1 \times \text{Volume}_1 = \text{Pressure}_2 \times \text{Volume}_2$$

$$P_1 \times V_1 = P_2 \times V_2$$

From this formula we can develop a formula for finding the theoretical amount of air that an air compressor can deliver per unit of time.

$$P_1 V_1 = P_2 V_2$$

Transpose the formula to find the final volume.

$$V_2 = \frac{P_1 V_1}{P_2}$$

$$V_2 = \frac{P_1 V_1}{P_2}$$

$$V_2 = \frac{15 \times V_1}{P_2}$$

where: pressure at inlet is 15p.s.i.a. or atmospheric pressure

$$V_2 = \frac{15 \times A_c \times L_s}{P_2}$$

where: volume = area of the cylinder X length of the stroke.

This formula will give you the theoretical amount of air discharged on each stroke. To find the amount per minute, multiply by the number of strokes per minute (N).

$$\frac{V_2}{\text{Min.}} = \frac{15 \times A_c \times L_s \times N}{P_2} \quad \text{or} \quad \frac{15 A_c L_s N}{P_2}$$

where:

$A_C = .7854 \times D_C^2$ = the area of the cylinder
L_S = length of the stroke
N = number of discharge strokes per minute

Example 1: What is the theoretical discharge of an air compressor in cubic feet per minute if it has a cylinder diameter of 10 inches and a stroke of 12 inches while running at 600 strokes per minute and discharging at 105 p.s.i.a.

$$A_C = .7854 \times D^2 = .7854 \times \frac{10}{12} \times \frac{10}{12}$$

$$L_S = \frac{12}{12} = 1 \text{ Foot}$$

$$N = 600$$

Note: Inches were changed to feet because we want cubic feet per minute.

$$\text{Cubic feet/min} = \frac{15 \times A_c \times L_s \times N}{P_2}$$

$$\text{Cubic feet/min} = \frac{15 \times .7854 \times \frac{10}{12} \times \frac{10}{12} \times 1 \times 600}{105}$$

$$\text{Cubic feet/min} = 46.75$$

Example 2: An air compressor with a 14-inch diameter cylinder and a 12-inch stroke runs at 150 double strokes per minute and discharges air into a receiver at 75 p.s.i.. What is the theoretical capacity for this compressor in cubic feet per minute?

$$A_C = .7854 \times D^2 = .7854 \times \frac{14}{12} \times \frac{14}{12}$$

$$L_S = \frac{12}{12} = 1$$

$$N = 300$$

$$P_2 = 75 + 15 = 90\text{p.s.i.a.}$$

Note: Double strokes and change of pressure to absolute.

$$\text{Cubic feet/min} = \frac{15 \times A_c \times L_s \times N}{P_2}$$

$$\text{Cubic feet/min} = \frac{15 \times .7854 \times \frac{14}{12} \times \frac{14}{12} \times 1 \times 300}{90}$$

$$\text{Cubic feet/min} = 53.45$$

Reference: *Steam, Air, and Gas Power*

Assignment:

1. Show how we used Boyle's Law to develop a formula for capacity of an air compressor.
2. Find the capacity in cubic feet per minute of the following air compressors:

	a.	b.	c.
Bore	6 inches	10 inches	20 inches
Stroke	4 inches	12 inches	16 inches
Speed	350 r.p.m.	300 r.p.m.	200 r.p.m.
Discharge Pressure	45 p.s.i.	75 p.s.i.	60 p.s.i.

Each compressor is double acting and discharges on each stroke.

Air Compressor Operation Assignment 13-C-1

Objective: Be able to start up and cut a compressor into a line already under pressure.

Information: In plants requiring large volumes of air, there will be times when you have two or three air compressors using a common aftercooler and receiver. Plant conditions will dictate when more than one machine will be required on the line to maintain the plant load. Under these conditions it may be necessary for the operator to start up a compressor and cut it in on the line that is already under pressure. This will have no resemblance to the procedure you would follow cutting a new boiler in on the line. Most large two-stage compressors will have synchronous motor drive. These motors have a very low starting torque and must be started under no-load conditions.

Using Figure 13-C-1-1, follow the startup procedure:

1. Check machine for rags or loose tools.
2. Check lubrication.
3. Crack cooling water (4)
4. Check discharge valve (2) to aftercooler is closed.
5. Check atmospheric vent valve (3) is open.
6. Check suction valve (1) is closed.
7. Then push "run" button.
8. When machine is up to speed, close atmospheric vent (3).
9. Open discharge valve (2) to aftercooler.
10. Open suction valve (1).
11. Close electric switch on automatic electric unloader.
12. Machine will now start to pump air.
13. Check lubrication and temperature of cooling water and make any adjustments needed.

To secure the machine:

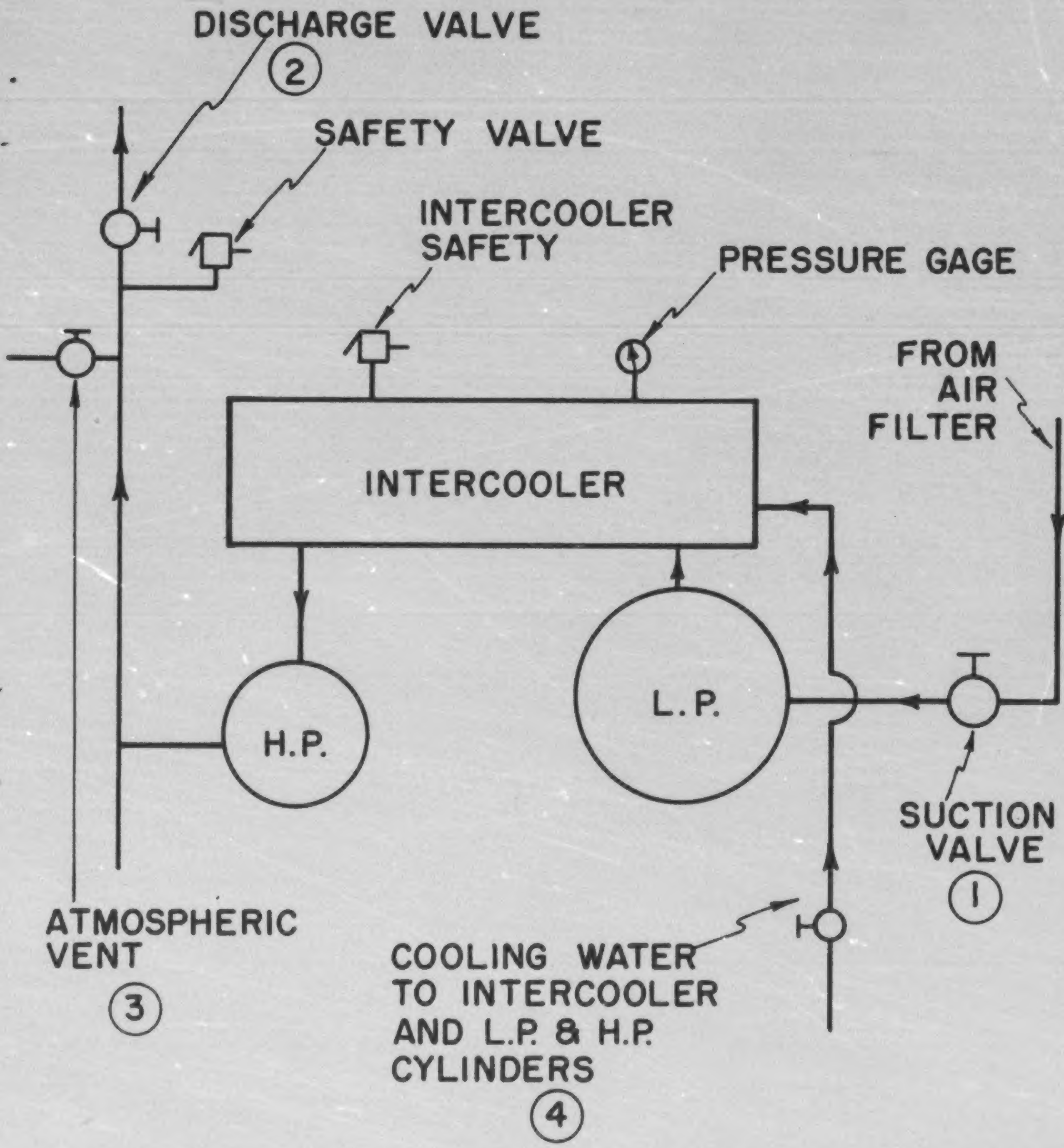
1. Open electric switch on automatic electric unloader. Machine will continue to run, but it will not be compressing air. Close the suction valve (1).
2. Close discharge valve (2) to aftercooler and line.
3. Open atmospheric vent (3).
4. Push "stop" button on synchronous motor; machine will stop.
5. Secure cooling water and wipe down machine.

Hourly readings must be taken on the pressure gage on the intercooler; on the discharge to aftercooler. Temperature readings must be taken on water leaving the intercooler and on water leaving the aftercooler. While taking these readings, it is also necessary that all lubrication be checked.

Reference: *Information data*

Assignment:

1. Discuss why it is necessary to always follow Step 1 in the startup procedure.
2. What purpose does the atmospheric relief valve serve?
3. Why do some plants have more than one compressor tied into a common receiver?
4. What would happen if you tried to start a synchronous motor-driven compressor under load?
5. What would a rise in cooling water temperature indicate?


DISCHARGE VALVE
②
SAFETY VALVE
INTERCOOLER SAFETY
PRESSURE GAGE
FROM AIR FILTER
INTERCOOLER
H.P.
L.P.
SUCTION VALVE
①
ATMOSPHERIC VENT
③
COOLING WATER TO INTERCOOLER AND L.P. & H.P. CYLINDERS
④

13-C-1-1

Routine Compressor Maintenance

Assignment 13-D-1

Objective:

1. Be able to describe the required routine maintenance for air compressors.

Information: Plant conditions will determine how often air filters on the suction side of the compressor must be cleaned. Due to the dirt in the air, some filters must be changed or cleaned every 30 days. In other locations it may only be necessary to clean filter only four times a year. With the oil bath filter, it is necessary to drain off all the oil and then clean out the filter bottom. You will be surprised at the amount of dirt found trapped here. After being thoroughly cleaned, a fresh supply of oil must be added. The oil used for compressor lubrication is special; it must have a high flash point to prevent compressor explosions. The manufacturer will recommend how often the oil must be changed. This is usually based on running hours on the machine. When this oil is changed, the sump must be carefully cleaned. If there is a screen filter, it must be removed and flushed. Some compressors will be splash lubricated; others will be pressure lubricated with a pump being driven off the compressor shaft; and still others will be a combination of both. splash and pressure lubrication. Careful attention to filters and oil changes will add to a longer trouble free life for your compressor.

Reference: *Ingersoll-Rand Catalog A-P-01S0*

Assignment:

1. How often must air filters be cleaned?
2. What makes compressor oil different from ordinary lube oil?
3. What does the manufacturer recommend doing:
   a. After 1st 50 hours
   b. After 1st 200 hours
   c. Every 4000 hours or at least once a year
4. Discuss operator's daily routine.
5. Discuss operator's other regular duties depending on operating conditions.
6. How can proper V-belt tension be checked?
7. What affects the life of V-belts?
8. Does the manufacturer recommend belt dressing? Explain.
9. If a machine requires 3 belts and only one belt is broken, can you just replace the one belt? Explain.

Electrical Safety Practices — Assignment 14-A-1

Objective: 1. Be able to explain the safety practices and procedures to follow when working with electric equipment.

Information: Electricity can be useful for man, or it can be extremely dangerous. In this modern world electricity is all around us, and without it we would be more or less at a stand still. It runs our machines and gives us light and heat, but it can also injure and possibly kill if it is handled carelessly. Safety practices and procedures for the handling of electrical equipment are set up in most plant safety programs to protect workers and operators of electrical equipment. As an example, the rules in our school plant are as follows:

1. Always check all power tools for proper grounding.
2. Never use a power tool, extension cord, or drop light with a frayed cord.
3. Never unplug any electrical cord by pulling on the wire cord; use the plug.
4. Never work on electrical equipment while standing in water.
5. Do not poke your fingers in electrical switches, starters, or sockets.
6. Do not work on live electric circuits; always pull circuit breaker, fuse or main switch.
7. Always check electrical equipment with tester after killing circuit to be sure that electricity is off.
8. Never pull a fuse by hand; use a fuse puller.
9. Do not work on the steam and water side of boiler with a drop light. Use a portable light or a low-voltage drop light.
10. Never put current to any project until it has been checked out by the instructor.
11. Do not handle capacitors until they have been discharged.
12. Protect all electrical equipment when washing down.
13. Never use a water extinguisher on an electrical fire.
14. If in doubt, stop and notify instructor.
15. Don't try to be a live wire; your fuse cannot be replaced!

When safety rules are followed, the chances of electrical accidents are reduced. Always be safe instead of sorry.

Assignment:

1. Why are safety rules necessary?
2. Why is electrical equipment grounded?
3. Give a reason why each of the numbered rules 2-13 is necessary.

Review of Basic Fundamentals of Electricity — Assignment 14-B-1

Objectives:

1. Be able to define voltage, amperage, ohm, wattage, direct current, and alternating current.
2. Be able to define Ohm's Law.
3. Be able to calculate problems using Ohm's Law and power equations.

Information: Let's review some of the basic facts of electricity. It is a form of energy and is convertable to other forms such as heat or mechanical energy. Electricity is a flow of electrons through a conductor.

The ampere is a unit that is used to express quantity or number of electrons that are flowing per unit of time. You may think of this in the same manner as gallons per minute in a water line. The volt is a unit that is used to measure the pressure differential between two points of a conductor. It is the force that is causing the electrons to move. You may also look at it as being similar to the pressure needed to have water flow in a pipe.

The ohm is a unit that is used to express resistance in a conductor to the flow of electrons. This is similar to the friction that occurs in pipes when water is passed through.

Power is the rate of doing work. The basic unit of electrical power is the watt. It can be found by multiplying the voltage times the amperage.

There are two types of electricity in use today – direct current and alternating currents. Direct current is when the electrons flow in one direction only. Alternating current is when the electrons flow momentarily in one direction and then change to the other direction.

The relationship of current, voltage, and resistance is given in Ohm's Law. It may be expressed by the following equations:

> Current equals the voltage divided by the resistance.
> Resistance equals the voltage divided by the current.
> Voltage is equal to the product of the current times the resistance.

Example 1: Find the current when the voltage is 12 volts and the resistance is 6 Ohms.

Equation $I = E/R$
Substitute $I = 12/6$
Solve $I = 2$ amps

Example 2: Find the resistance when the voltage is 12 volts and the current is 2 amps.

Equation $R = E/I$
Substitute $R = 12/2$
Solve $R = 6$ Ohms

Example 3: Find the voltage when the current is 2 amperes and the resistance is 6 Ohms.

Equation $E = IR$
Substitute $E = 2 \times 6$
Solve $E = 12$ volts

Power in an electrical system is measured in watts and is the product of the voltage times the amperage.

Watts = volts × amperes
$W = E \times I$

If Ohm's Law, $E = IR$, is substituted into the power equation we can express the power in a circuit by using the following equations:

1. $W = E \times I$
2. $W = I^2 \times R$
3. $W = E^2/R$

The power using the above equations will be given in watts. This may be converted to kilowatts by dividing watts by 1000.

1 Kilowatt = 1000 watts

Reference: *Electricity Fundamentals*

Assignment:

1. Define the following terms:
    - a. Voltage
    - b. Amperage
    - c. Ohm
    - d. Wattage
    - e. Direct current
    - f. Alternating current
2. Write the Ohm's Law equations for finding:
    - a. Voltage
    - b. Current
    - c. Resistance

3. What current will flow through a coil having a resistance of 12 Ohms if the applied voltage is 48 volts?
4. What is the resistance of a light bulb with 1 ampere flow at 110 volts?
5. How many volts will be required to produce 1.5 amps through a coil with 7 Ohms resistance?
6. The resistance in a circuit is 100 Ohms and it is connected to a 4 volt battery. What is the amperage in the circuit?
7. How many watts would be used in each of the following circuits:
    a. 120 volt at 5 amps
    b. 1000 Ohm resistor at 1 amp
    c. 6-Ohm resistor at 12 volts
    d. 9 amps at 120 volts
8. What is the resistance of a 60 watt, 120 volt lamp?
9. Find the current for a 800 watt, 120 volt toaster.
10. A 120 volt circuit is supplying the motor with 5 amperes of current. How many kw/hr. of energy is the motor using in 24 hours?

Objectives:

1. Be able to identify electrical circuits.
2. Be able to solve problems in series, parallel, and series-parallel circuits for voltage, amperage, and resistance.
3. Be able to solve problems for total power in a circuit.

Information: Let's review the series, parallel, and series-parallel circuits. In the series circuit, there is only one path for the current to take. Each device is connected together in a continuous path. In the parallel circuit, each path or branch is connected directly across the voltage source. The series-parallel circuit is a combination of the series and parallel circuits into one circuit. The series, parallel, and series-parallel circuits are shown in Figure 14-B-2-1.

The total resistance in a series circuit is the sum of the resistances.

$$R_t = R_1 + R_2 + R_3 \text{ etc.}$$

The current in a series circuit depends upon the voltage applied and the total resistance. It is found by using Ohm's Law:

$$I = \frac{E}{R_t}$$

The sum of the voltages across each resistor is equal to the applied voltage.

$$E = E_1 + E_2 + E_3 \text{ etc.}$$

The total resistance in a parallel circuit can be found by using the following equation:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}$$

The current in a parallel circuit can be different in each branch. The current in each branch is dependent on the resistance and the voltage in that branch. The voltage is the same across each branch in a parallel circuit.

Series-parallel circuits can be quite complicated. They may be solved by applying the same basic rules that we used in solving problems in series and parallel circuits. The series-parallel circuit has to be simplified by separating and solving the series and parallel problems within it.

Facts to remember in a series circuit:

1. The current in a series circuit is the same throughout the circuit.
2. Total resistance is the sum of the resistors in a circuit.
3. The sum of the voltage across each resistor is equal to the applied voltage.

Facts to remember in a parallel circuit.

1. The current in each branch is dependent upon the resistance in each branch.
2. The total current is the sum of the currents through each branch.
3. The reciprocal of the total resistance is equal to the sum of the reciprocal resistances in each branch.
4. The voltage is the same across each branch.

Facts to remember in a parallel series circuit:

1. Simplify into series or parallel circuits.
2. Apply same rules as for individual circuits.

Power in any circuit may be found by using the following equation:

$$W = E \times I_t$$

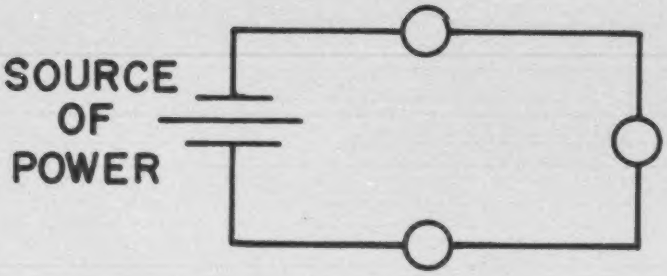
The voltage (E) is the applied voltage and the amperage (I) is the total amperage in the circuit.

Reference: *Stationary Engineering, Environmental Control, Refrigeration – Science Manual – 1*

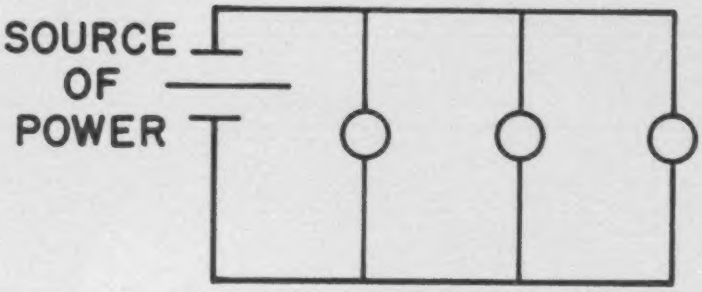
Note: Sample problems on series, parallel, and series-parallel circuits may be found in this manual.

Assignment:

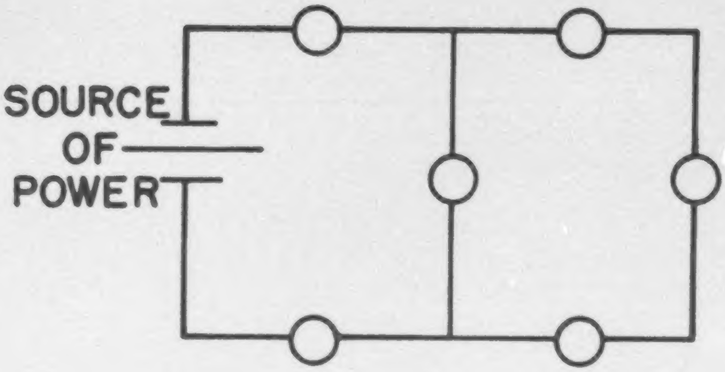
1. In Circuit "A", Figure 14-B-2-2, solve for:
    a. Total resistance
    b. Voltage across each resistor
    c. Total current
    d. Current through each resistor
    e. Power in the circuit.
2. In Circuit "B", Figure 14-B-2-3, solve for:
    a. Total resistance
    b. Voltage across each resistor
    c. Total current
    d. Current through each resistor
    e. Power in the circuit.


SOURCE
OF
POWER

SERIES
CIRCUIT

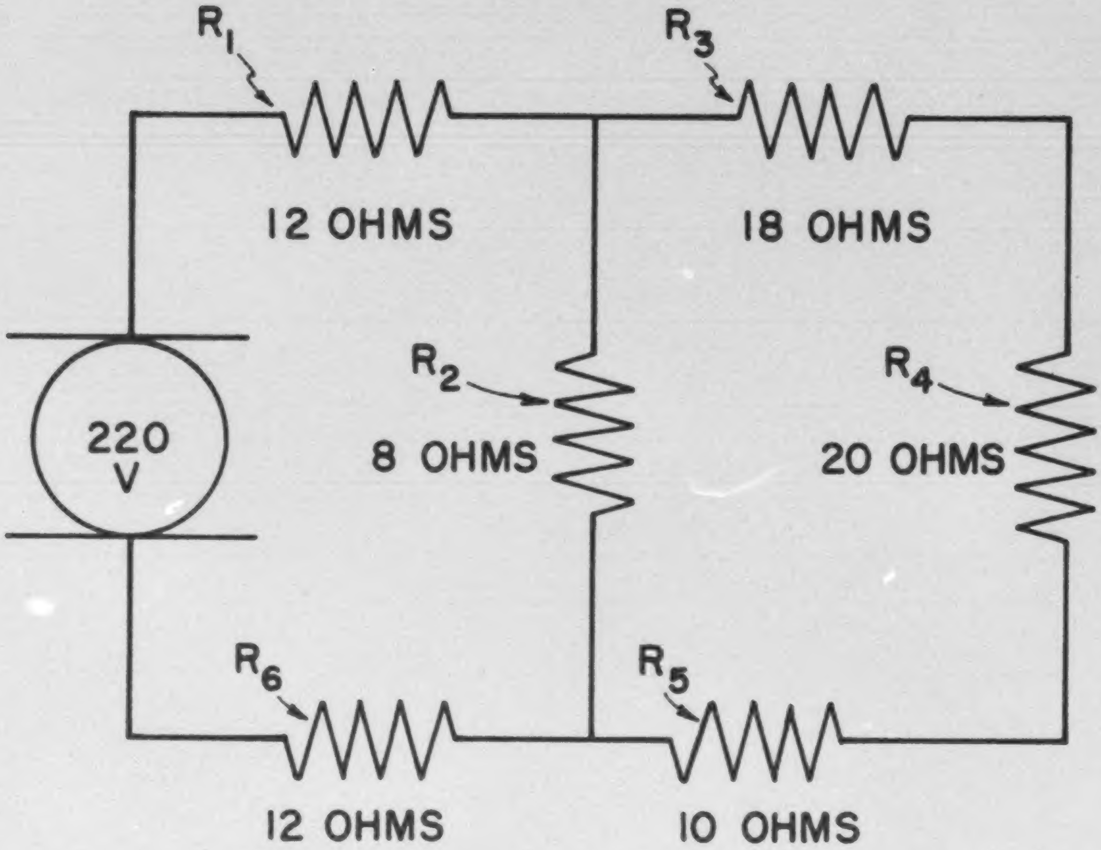

SOURCE
OF
POWER

PARALLEL
CIRCUIT


SOURCE
OF
POWER

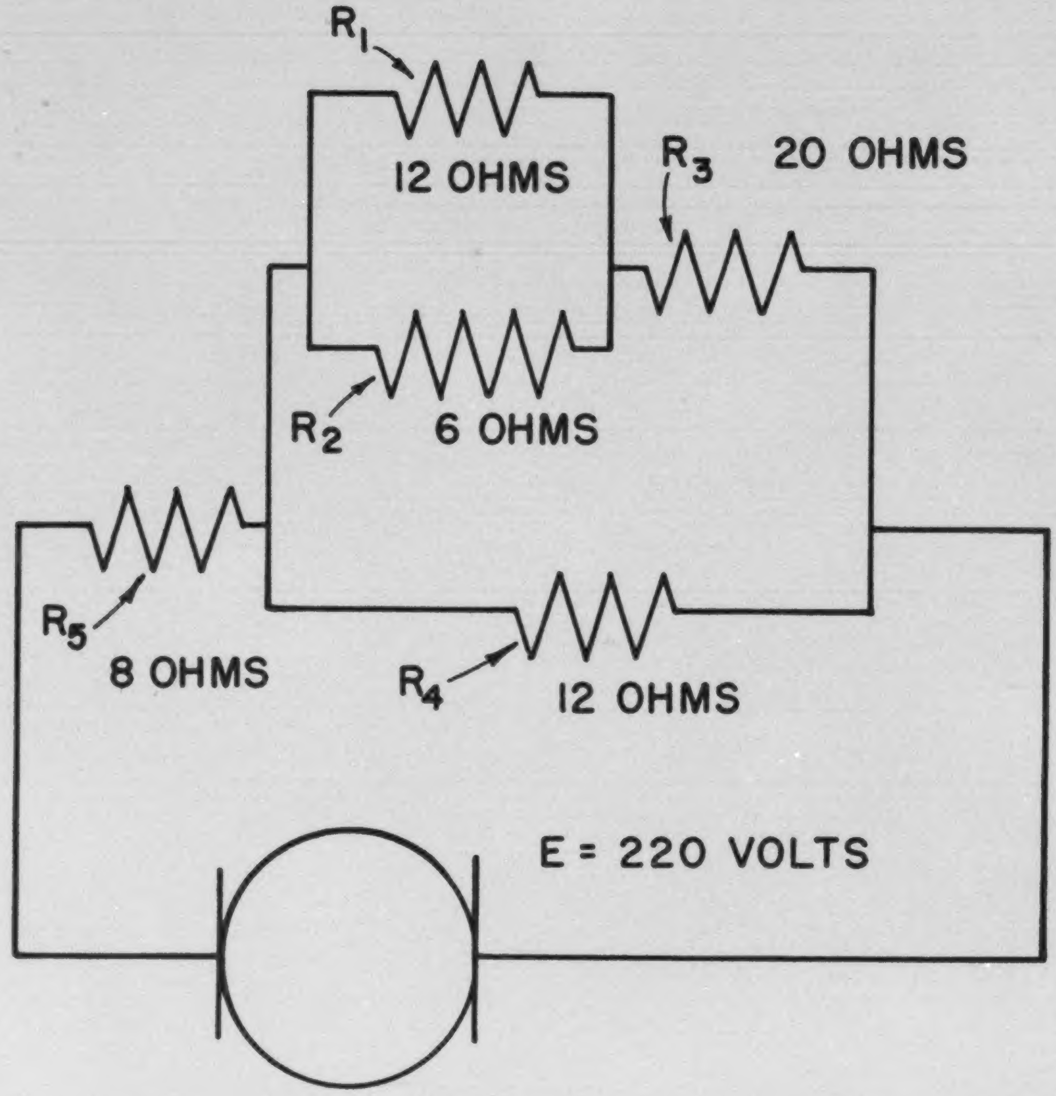
SERIES
PARALLEL
CIRCUIT

14-B-2-1


R1
12 OHMS
R3
18 OHMS
R2
8 OHMS
R4
20 OHMS
220 V
R6
12 OHMS
R5
10 OHMS

CIRCUIT A

14-B-2-2


R1
12 OHMS
R3
20 OHMS
R2
6 OHMS
R5
8 OHMS
R4
12 OHMS
E = 220 VOLTS

CIRCUIT B

14-B-2-3

Objective: 1. Be able to describe how the pressure-trol, aquastat, and low water cutoff are connected in the burner control circuit.

Information: On most steam generating package boilers, the following controls will be wired into the control circuit:

1. A pressure-trol – an automatic switch that closes or opens depending on the pressure within the boiler.
2. An aquastat – an automatic switch that closes or opens depending on the temperature within the boiler.
3. A low water cutoff – an automatic device that opens or closes a switch depending upon the level of water within the boiler.
4. A manual on-off switch – for starting and stopping the burner.

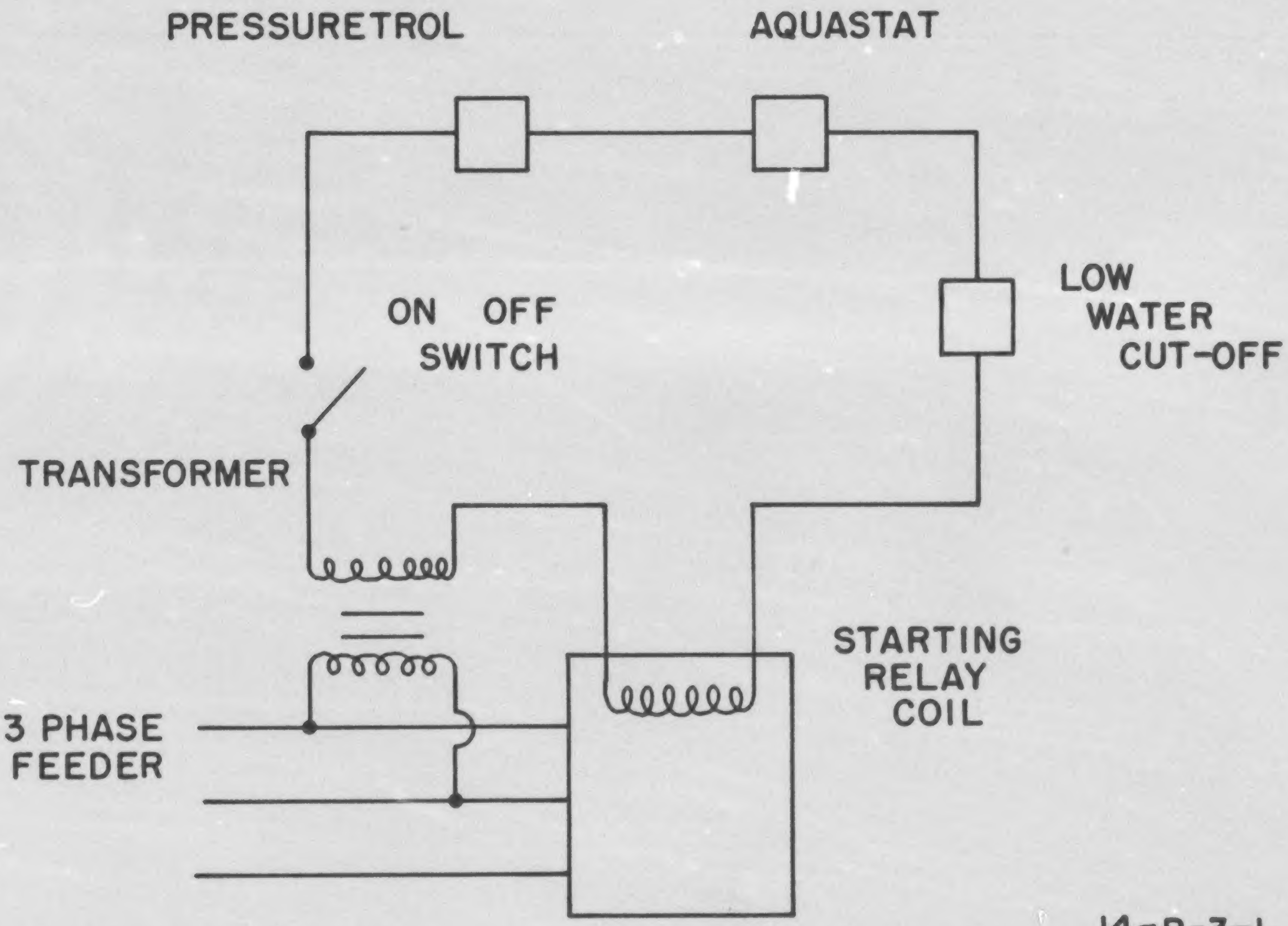
They are connected in series as in Figure 14-B-3-1.

The electrical connection for this circuit comes from a transformer. This is done to insure a positive deenergizing of the circuit in the event of a ground. The pressure-trol, aquastat, low water cutoff, and the on-off switch are in series as shown with the burner circuit relay coil. When all switches are closed and the coil is energized, the relay pulls in the burner circuit contacts and starts a sequence of burner operation. If the steam pressure reaches a preset point, the pressure-trol will open thus shutting down the burner. The aquastat opens on a rise in temperature. This control is normally only used to keep a boiler hot for standby use; it is usually in a closed position during normal operation. In the event that low water condition occurs, the switch will open stopping the burner. These controls all serve a safety purpose as well as an operational purpose. Do not block or jump a control of this type; it can have disastrous results.

Reference: *Manufacturer's Instruction Manual*

Assignment:

1. What type of circuit is used in the burner control circuit?
2. Show with a line drawing how No. 3 burner control circuit is wired.
3. What purpose does the following serve in the circuit:
   a. Pressure-trol
   b. Aquastat
   c. Low water cutoff
4. Why is it important to have a transformer in this system?


PRESSURETROL
AQUASTAT
LOW WATER CUT-OFF
ON OFF SWITCH
TRANSFORMER
STARTING RELAY COIL
3 PHASE FEEDER

14-B-3-1

Objectives:

1. Be able to explain the purpose of starters, relays, and switches.
2. Be able to explain how the starters and relays function.

Information: A relay is an electromechanical switching device that can be used as a remote control. It consists of contacts and a magnetic coil that closes or opens the contacts. A relay may have several pairs, or as little as one pair, of contacts depending upon its use. The coil is normally energized by a control circuit such as the one discussed in Assignment 14-B-3. There are many types of relays such as time, current, voltage, power, and a number of others that are designed for special functions. For our purpose, relays are used for starting circuits, switching circuits, and as safety devices.

A relay, with overload protection and a power supply that is connected through it to a motor, is known as a starter. The overload protection is usually heaters that if overheated by excess current cause the relay to drop out disconnecting power to the motor. This prevents possible damage to motor and wiring.

The switches used for opening or closing electric circuits may be manual or automatic. An example of a manual switch is the common toggle switch found in our homes for lights, etc. A pressure-trol is an example of an automatic switch. Electric switches can be single-pole, single-throw, or double-throw. Three-pole, four pole, single-throw, double-throw switches are for special applications.

Reference: *Industrial Electricity*

Assignment:

1. What is a relay?
2. Where are relays used?
3. Name at least four relays that are used in our boilerroom.
4. What is a starter?
5. How does a starter work?
6. Are all switches the same? Explain.
7. Name the various types of switches in our boilerroom.

Objectives:

1. Be able to explain the purpose of fuses, breakers, and heaters.
2. Be able to explain how fuses, breakers, and heaters function.

Information: Fuses, circuit breakers and heaters are overload protective devices. They prevent damage to electrical equipment such as motors, coils, and wiring; and in many instances they prevent fires.

A fuse contains a metal that is inserted in series with a circuit. If the current is increased beyond a specific value for a definite period of time, the metal will melt or break, which opens the circuit and prevents damage. Some fuses used for motor protection have a time delay built into them. This is to prevent the fuse from blowing on startup when a high current is used.

A circuit breaker is an electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. The breaker remains closed until the current reaches the set point, and then it trips allowing a spring to open the breaker. Circuit breakers can be equipped with a time-delay device for high current starts.

Heaters are thermal overload devices that are usually used in starters. They are connected in series in the motor circuit. They open the holding coil circuit in the relay when the motor is overloaded. This prevents damage or burnout of the motor. When dealing with fuses, circuit breakers, or heaters, it is very important that the proper size be installed. Your electric wiring and equipment is not protected when oversized fuses, circuit breakers, and heaters are used. If in doubt, follow the manufacturer's specification or check with the local electrical code.

Reference: *Electricity Fundamentals*

Assignment:

1. What is the purpose of a fuse, and where are they used?
2. What is the purpose of a circuit breaker?
3. What advantages or disadvantages does a circuit breaker have over a fuse?
4. What is the purpose of a heater and where are they used?

Objectives:

1. Be able to describe the types of basic electrical meters.
2. Be able to explain the uses of basic electrical meters.

Information: The basic instruments for the measurement of electricity are:

1. Voltmeter – measures the difference of voltage between two points in a circuit. This instrument is used to check the voltage, fuses, or a possible break in the circuit.
2. Ammeter – measures the current in any part of a circuit. It is usually used to check for high current in a circuit.
3. Ohmmeter – measures the amount of resistance in a part of a circuit or in a complete circuit. Continuity can also be checked with this instrument.
4. "Megger" or megohmmeter – used to measure resistance in a circuit. This instrument is used to check for a breakdown of insulation on coils, motors, generators, and relays. When insulation breaks down, there is a leaking of electricity to the ground. This is especially true in high voltage systems.

When trouble shooting electrical circuits, it is necessary to use one or all of the instruments mentioned. Never use an instrument on a live circuit unless you are familiar with its use. They are expensive to repair, and extensive damage can result from improper use.

Reference: *Electricity Fundamentals*

Assignment:

1. What instruments are used in electrical testing?
2. Explain the use of each instrument.

Objectives:

1. Be able to take over a shift.
2. Be able to perform the routine duties of a boiler operator.

Information: The Watch Engineer or Fireman must be prepared to take over a shift and follow a certain procedure. This procedure is important for him to follow so that the boiler plant will run safely and efficiently. The following numerical order shows the steps that he should follow:

1. Report to work 10 minutes early to relieve the Watch Engineer.
2. Check water level in boiler by blowing down the water column and gage glass.
3. Test low water cutoff control.
4. Inspect and check feed pump, bearings, lube oil level, packing glands, excessive vibration, and feed pump pressure. Inspect and check fuel oil pump, fuel oil pressure bearings, and excessive vibration.
5. Check Chief Engineer's Log for outstanding instructions.
6. Check and listen for any unusual noises or steam leaks.
7. Check water level in open type, feed-water heater or makeup feed tank.
8. Check burner and fire for correct flame including fuel temperatures and pressures.
9. Walk around the boilerroom, and make sure that all machinery is in good operating condition.
10. Check and determine that the fuel supply is adequate.

The routine duties of the boiler operator are clearly outlined in the State Rules and Regulations, which are enforced by the New Jersey Department of Labor, Mechanical Inspection Bureau. The regulations state that at no time shall the boiler plant be operated in an unsafe manner. The duties of the boiler operator will vary from plant to plant, but there are certain duties which will always remain the same. The following is a list of those duties and responsibilities:

1. Maintain the proper water level in the boiler at all times.
2. Never leave the boilerroom for a period longer than that which is considered safe.
3. Carry out the Chief Engineer's written or verbal instructions.
4. Maintain the correct operating steam pressure.
5. Test the low water cutoff control.

6. Test and maintain the feed-water regulator in good operating condition.
7. Maintain the burner in good operating condition.
8. Maintain the correct fuel pressures and temperatures.
9. Keep a record of the fuel oil on hand.
10. Check and maintain the amount of makeup feed being used. Always maintain an adequate supply of feed water.
11. Maintain correct feed-water temperature.
12. Periodically inspect feed-water pump.
13. Periodically inspect fuel oil pump.
14. Periodically check draft fans.
15. Maintain the proper draft in the boiler.
16. Check fire in furnace periodically.
17. Follow Chief Engineer's instructions for correct feed-water treatment and boiler blowdown.
18. Use soot blowers when scheduled.
19. Stay alert for any unusual occurrences such as steam load changes, steam leaks, low water in the boiler, machinery failures, etc.
20. Always operate the boiler plant in a safe and efficient manner.

References: *New Jersey Rules and Regulations*
Boiler Room Questions and Answers
Low Pressure Boilers

Assignment:

1. Tell who enforces the boiler plant laws in the state, and explain the purpose of these rules and regulations.
2. Why is it important that the boiler operator know the proper procedure for taking over a boilerroom shift?
3. Discuss some of the routine duties and responsibilities of a boiler operator. Tell why he must carry out the instructions of the Chief Engineer.
4. What are the first 10 things you would check when entering a strange boilerroom?

Objectives:

1. Be able to describe the routine procedure for starting up a boiler plant.
2. Be able to describe the routine procedure for shutting down a boiler plant.
3. Be able to describe the routine procedure for laying up a boiler – wet or dry.

Information: One of the most difficult jobs for a fireman is the starting up of a dead plant, completely securing a live plant, and laying up the boilers.

The startup procedure for any boiler plant will vary from plant to plant. It will depend upon such conditions as the number of boilers, the size of the plant, the type of fuel burned, and if the plant is operated automatically or manually. The procedure and method may vary, but the same basic things must be done in as safe and efficient a manner as possible.

Prepare the fuel before "firing up" the boilers. This procedure will be determined by the type of fuel being used.

When gas is used, little or no preparation is necessary except to insure that the correct pressure is at the burner.

In burning coal, an adequate supply of coal must be on hand at the stoker or at the pulverizing mill. In the case of the stoker-fired boiler, a wood fire must be started in the furnace to ignite the bed of coal.

Heavy oil-fired boilers must have the oil circulating and be at the proper temperature before it can be burned. This means that the electric fuel oil heaters will have to be used or lighter grade of oil such as number 2 or 4 used when first lighting off the boiler. All fuel oil strainers should be cleaned as well as the fuel oil burner assembly.

The boilers should be checked for any missing or open inspection openings. All stack coverings should be removed and hand operated dampers should be opened. The correct water level should be showing in the gage glass. The automatic non-return valve and the main steam stop valves in the main steam line should be opened and closed. All drains in the main steam lines and header should be opened.

The feed water system should be checked to see that the system is lined up to the boilers and the proper valves are open. Feed pumps, feed water regulators should be inspected. There should be an adequate supply of water in the feed water heater and the make-up feed tank.

The boilers should be purged of all combustible gases before the burner is fired.

Check all the valves on the boilers to insure their proper position; the bottom blown down valve should be closed. The water column, gage glass, steam pressure gage, air cocks and super heater drain valves should be in the open position.

Warm the boilers up slowly to prevent uneven expansion and contraction. Open the automatic non-return valve.

Maintain the normal water level in the boiler. When the steam pressure is about 25 lbs. close the air cocks. Open the steam line drain between the non-return valve and the main steam stop-valve. Open the equalizing line around the main steam stop-valve. When the boilers are up to pressure open the main stop-valve. All super heater drain valves should be closed when steam from the plant is being used.

At this time the automatic combustion controls and feed-water regulator should be checked for proper operation along with all boilerroom machinery.

During this period of time the boiler operator has to be constantly alert for any sudden and unusual occurrences, for at no other time will the operation of the boiler plant be more critical than at start-up. All boilerroom machinery must be watched very closely. If automatic controls are used they should be put into operation, and watched very closely. Nothing should be taken for granted.

Shutting down a boiler plant properly will require certain things to be done. This may vary from plant to plant depending upon the size of the plant, length of shut-down and time of year. It must be done so that whenever the plant is started up again there will be no damaged equipment due to improper shutting down of the plant.

The fuel system should be shut down and the burners cleaned. How this will be done will be determined by the type of fuel used: coal, oil or gas. A gas system will require little or no attention. A stoker will require cleaning and lubrication. A fuel oil system will require the fuel oil strainers cleaned and the burner cleaned. In the case of a heavy oil system the lines should be blown out by air to ensure that all lines will be clear when starting-up.

The boiler steam stop valves should be closed and all steam line drains opened. The superheater drain should be opened as soon as the boiler is shut down. When the steam pressure is down to 25 lbs. the air cock should be opened.

While the boiler is cooling down, the water level should be maintained at the normal operating water level. When the boiler has cooled down sufficiently, the feed pump and the feed water system should be shut-down and all valves in the system closed.

When the boiler has cooled off enough to enter it, the fireside should be opened up and cleaned including the breeching and the base of the chimney. After cleaning the fireside, all access doors and panels should be put back and the boiler fireside closed up making sure that all tools have been removed.

The water side of the boiler should be opened up, but make sure that there is no pressure or vacuum in the boiler. All inspection plates and covers are removed, and the water side is flushed out to remove any mud, sludge or scale in the boiler. Close it up tight making sure that all tools and rags have been removed.

Boilers that are to be out of service should be protected against deterioration if they are not laid up properly, they could be damaged due to oxygen pitting or sulfur attack. There are two methods of laying up a boiler – wet or dry. Regardless of which method is used, the boiler must be thoroughly cleaned on both the fire-and the water side. It should also be inspected. Any repairs needed should be made at once. Then you may proceed to lay it up in the manner decided on. When you have to lay up a boiler, keep in mind whether it will be out of service for a long period of time. For example, is there danger of freezing? Is it necessary to bring it back into service on short notice? After you have answered these questions, you can decide on the best method to use in laying up the boiler.

References: *Steam Plant Operation*
Low Pressure Boilers
A.S.M.E. Code, Section 7
New Jersey Rules and Regulations

Assignment:

1. Why would it be necessary for a boiler to be inspected if the plant had been laid up for a year or two.
2. Why is it so important to remove all ash, coal, and soot when laying up a boiler?
3. When would you recommend laying up a boiler wet? Dry?
4. What does the A.S.M.E. Code state in respect to chemicals to be used when laying up a boiler wet?
5. What does the A.S.M.E. Code state in respect to chemicals to use when laying up a boiler dry?
6. Explain the procedure you would follow when laying up a boiler:
   a. Wet
   b. Dry
7. Why is it necessary to purge a boiler that has been off the line and out of service?
8. Why does the boiler operator have to waste time making checks before he lights off a dead plant?

High and Low Water Condition in a Boiler — Assignment 15-C-1

Objectives:

1. Be able to handle low water in a steam boiler.
2. Be able to handle high water in a steam boiler.

Information: Steam boilers are equipped with low water cutoff devices, alarms, or high and low water whistles. These devices help the boiler operator do a safer job and give the boiler better protection. Quite often many boilers suffer a low or high water condition. This could be due to operator neglect, control, or boiler failure. The extent of overheating or damage to the boiler will be determined by how quickly the operator reacts to correct the condition that exists.

Any time the operator cannot see water in the gage glass, a low water condition exists. He should know the correct procedure to follow immediately. By taking immediate corrective action, he may save the boiler from excessive damage or prevent damage from occurring.

The correct method for handling a low water condition in a boiler is outlined in the references. It will vary to some extent on the type of boiler and the fuel being used. When this condition occurs, every second counts toward saving the boiler from being seriously damaged. When in doubt about the water level in a boiler, always secure the fires immediately.

The danger existing with high water in a steam boiler is entirely different from a low water condition. With low water the steam boiler drum, tubes, and furnace are endangered. With high water it is the superheater tubes, headers, and steam equipment such as pumps and turbines that are endangered. Any time that the water level in a steam boiler is ¾ of a glass or higher, there is a strong possibility that the water is being carried over with the steam. The level should be corrected immediately, even if it necessitates using the bottom blowdown valve. A normal water level in a steam boiler will vary from 1/3 to 1/2 of a gage glass. High water alarms and whistles are used to indicate high water in most modern plants today.

References:

Steam Plant Operation
Standard Boiler Operators Questions and Answers

Assignment:

1. What is a low water condition in a steam boiler?
2. What is a high water condition in a steam boiler?

3. What could possibly cause a low water condition in a steam boiler?
4. What could cause a high water level.
5. What is the danger from low water?
6. What is the danger from high water?
7. What devices are used to warn the operator or prevent damage to steam boilers from low or high water levels?

Objective: 1. Be able to know what to do if you have a flame failure.

Information: If you entered a boilerroom and found the boiler down (not operating) with little or no pressure, it would be off for one or two reasons. It would be off because of low water or flame failure. Low water conditions have been discussed; now we will discuss flame failure conditions. Flame failure is as the name suggests – no flame – no fire; for some reason the fire has been lost. A flame failure can lead to a furnace explosion. A furnace explosion is the ignition and instantaneous combustion of explosive or highly flammable gas, vapor, or dust accumulated in a boiler setting. In minor explosions, which are referred to as puffs, flarebacks, or blowbacks, flames may blow suddenly for a distance of many feet from all firing and access doors. Furnace explosions can and do cause serious and costly damage to boiler plants in addition to causing personal injury. The main causes of furnace explosions are lack of adequate purge, human error, flame failure, or a faulty fuel system.

Not all boilers are equipped with automatic flame failure controls. Small package boilers will be equipped with a fire-eye or similar device that will shut the main fuel valve in the event of pilot failure or loss of the main flame. Large plants rely on the operator to handle flame failures safely.

Let's look at some reasons for flame failures in a plant:

1. Oil fired:
    a. Cold oil
    b. Water in oil
    c. Air in oil lines
    d. Clogged strainer
    e. Clogged burner tip
    f. Loss of oil pressure
2. Gas fired:
    a. Low pressure in gas lines
    b. Water in gas
3. Pulverized coal:
    a. Wet coal
    b. Loss primary air
    c. Loss of coal to mill due to feeder failure or blockage

In a plant protected by automatic controls, the operator checks the firebox for signs of excess fuel and then resets his controls and lets the controls put the burner through a purge cycle and then through a firing cycle. In a plant that has no automatic shutdown, the operator must secure the fuel. Then he must manually purge his boiler to prevent a furnace explosion. It is necessary that the operator be thoroughly familiar with his equipment and follow the manufacturer's advice on length of purge and number of air changes required before attempting a new light-off.

References: *A.S.M.E. Code*, Section 7
Low Pressure Boilers
Combustion Engineering

Assignment:

1. Discuss two reasons for a boiler being off.
2. What are some reasons for flame failure?
3. What is a furnace explosion?
4. Discuss in detail how you would prevent a furnace explosion on a completely automatic boiler.
5. Discuss in detail how you would prevent a furnace explosion in a large boiler with no flame failure protection.

Objectives:

1. Be able to explain why the fire side and the water side of boilers must be kept clean.
2. Be able to explain the necessity of boiler inspection.
3. Be able to explain the purpose of boiler layup.
4. Be able to replace boiler gage glass.

Information: When you buy a new car, the manufacturer supplies you with an owner's manual. This manual tells you what the service requirements are for your car. If you expect your car to give you a long trouble free life, you take care of it by following the recommended maintenance policy.

Well, a boiler is no different from a car; it too requires certain minimum care. To prevent corrosive attacks of sulfur in the ash, coal, or soot, the fire side must be cleaned. This will also increase the efficiency by cutting down on fuel consumption because soot is an insulation and retards the transfer of heat. Whenever a boiler is off the line, the fire side should be inspected and cleaned. The water side of a boiler will, after a period of time, build up deposits of sludge and sediment. This is the result of feed-water treatment. The feed-water, when properly treated, turns the scale-forming salts into a non-adhering sludge which stays in suspension and usually most of it is removed by bottom blow downs. If by chance the feed-water treatment is neglected, the boiler will then have scale deposits building up on the heating surface. These scale deposits will increase fuel consumption and will lead to overheated boiler metal. Burned out tubes and even a boiler explosion could result. The boiler should be scheduled for some down time between inspections where the waterside can be checked. It can either be flushed or, if scale is present, the tubes should be turbined.

The State of New Jersey puts boilers under the jurisdiction of the Mechanical Inspection Bureau. This agency requires that all high-pressure boilers be inspected internally and externally once a year. This inspection is carried out either by a State Inspector, or an Insurance Inspector. A report is then filed with the Mechanical Inspection Bureau. If the boiler is found fit to operate, the State issues a boiler certificate which means the boiler may be used for another year. These boiler certificates by law must be posted in the boilerroom. Failure to post a boiler certificate will result in a $50 fine for the first offense.

It is the operator's responsibility to prepare the boilers for inspection. When you are ready, notify the inspector so an appointment can be made.

The boiler must be opened up on both the fire and water side, and it must be thoroughly cleaned. All plugs on cross connections to the water column, feed-water regulator, gage glass, and low water cutoff must be removed. The feed-water regulator and low water cutoff float chambers must also be opened for internal examination. The operator should be on hand to assist the inspector, and he should point out any trouble spots he may have found so that they can be checked out.

Some safety rules to follow when getting a boiler ready for inspection are:

1. Always cool a boiler slowly.
2. Do not allow a vacuum to form on a boiler coming off the line.
3. Secure, lock, and tag out the main steam stop-valves.
4. Secure, lock, and tag out the feed-water valves to the boiler.
5. Never dump a hot boiler.
6. Never dump a boiler unless you are ready to open and flush it out.
7. Always check to make sure the air cock is open before opening the manhole cover.
8. After dumping, secure, lock, and tag out bottom blowdown valves, or remove the valves and blank flange the blowdown lines to blowdown the tank.
9. Never enter steam and water side of boiler until "YOU" have checked to make sure stop valves, feed-water lines, and bottom blowdown lines are properly secured.
10. Never enter steam and water side with a drop light. Use a spot light or a low voltage drop light.
11. Always use proper ladders or scafolding for cleaning.

If after inspection, the boiler is to be laid up, follow the procedure as outlined in Assignment 15-A-2.

If you notice the gage glass is dirty or has been leaking when preparing the boiler for inspection, it should be either cleaned or replaced. How this is done will depend on the type of glass you have. Flat type gage glasses are usually kept as a spare unit. The holder and glass are installed by just breaking a union on the steam connection and one on the water connection. The new unit is then installed and the old one taken down on a work bench and opened up and new gaskets, mica, and glass installed.

A tubular gage glass is changed by:

1. Remove gage glass nuts.
2. Remove old glass.
3. Remove old gage glass washers and install new ones.
4. Put in new glass.
5. Tighten gage glass nuts hand tight and then turn with a wrench.

Note: If a gage glass must be cut to size, it is cut ¼" shorter than the inside measurements.

If a glass must be changed with a boiler under pressure, follow the same basic procedure outlined above. The only difference is you must first shut the water and steam valve to the gage glass and then open the gage glass blowdown valve. After the glass is installed, it must be warmed up as follows:

1. Crack steam to gage glass.
2. After glass has had a chance to warm up, open water and steam to gage glass.
3. Close gage glass blowdown valve.
4. Check for leaks.

Note: Whenever working on a gage glass, you should always wear face or eye protection. If a gage glass under pressure ruptures, glass will go all over the place.

References: *A.S.M.E. Code,* Section 7
Steam Plant Operation
Low Pressure Boilers
Elementary Steam Power Engineering

Assignment:

1. Why must the fire side be protected from ash, coal, and soot deposits.
2. What is the cause of scale formation in the water side of a boiler.
3. Where does sludge and sediment come from, and how is it removed from a boiler?
4. How often must boilers be inspected in this state?
5. Can a boiler be operated without a boiler certificate?
6. Who issues a boiler certificate, where must it be posted, and what are penalties for failing to post?
7. Why can't you dump a hot boiler?
8. Why should you flush a boiler as soon as you dump it?
9. If a gage glass has to be cut to size, how is it measured?
10. How is a gage glass warmed up?

Burner Routine — Assignment 16-B-1

Objective: 1. Be able to explain the burner routine for rotary cup, air atomizing, and gas burners.

Information: The purpose of any burner is to deliver fuel to the firebox. It must be in sufficient quantity, mixed with the proper amount of air, and in the proper condition to burn. It is the operator's responsibility to become familiar with the burners in his plant and the proper cleaning procedure. Basically burner routine consists of cleaning burner tips, ignition electrodes and strainers; checking ignition gap; keeping pilot lines clear and fire-eye ports clear; and maintaining oil level in sumps. It will also be necessary to periodically dump, flush, and renew oil in sumps. The forced draft fan of rotary cup burners must be clean, and the line going to the air switch must be removed and blown out at regular intervals.

References:
Rotary Cup Burner Manual
Air Atomizing Burner Manual
Gas Burner Manual

Assignment:

1. Discuss the following rotary cup maintenance:
   - a. General
   - b. Daily
   - c. Every three weeks
   - d. Every three months
   - e. Annual
2. Discuss the following air atomizing burner maintenance:
   - a. Metering oil pump
   - b. Primary air pump
   - c. Air pump lube system
   - d. Oil-air tank
   - e. Oil nozzle
3. Discuss the following gas burner maintenance:
   - a. Gas lines to burner
   - b. Pressure regulators
   - c. Pilot lines to burner
   - d. Ignition electrode gap

Objective: 1. Be able to explain basic valve care.

Information: Valve care and maintenance is very important in a steam boiler plant. The operator has to control the flow of various liquids and gases. Sometimes he has to close or open a valve, and at other times use it to throttle the flow. All valves should be in good working order for safety and efficiency, The following are a few do's and don'ts when operating:

1. Never use undue force when first opening or closing a valve. If it is that difficult to move, it requires servicing.
2. Never use a gate valve for throttling service; it will usually leak around the gage afterwards.
3. Apply proper lubricants to packings as per manufacturer's specifications.
4. Never tighten packing gland too tight. Even if you do not crack the gland, you will not be able to turn the stem.

Service and maintenance should be performed when necessary to:

1. Replace packing or gland.
2. Replace gaskets.
3. Replace or regrind seats, gates, or discs.
4. Replace stem.

On automatic valves, such items as diaphragms and pilot valves will also need attention on a regular basis. Always renew gaskets before assembling a reconditioned valve. This is also true for line flanges on a flange connected valve.

Reference: *Steam Plant Operation*

Assignment:

1. Why is it important to have all valves functioning properly?
2. What would be the result of using too much force on the wheel of a hand valve?
3. Why is a gate better suited for on-off operation than throttling service?
4. If a packing gland still leaked after tightening, what would you do?
5. Name all the parts of a valve that require periodic servicing.

Objective: 1. Be able to explain the basic care and service of pumps.

Information: An operator of a steam boiler is in charge of feed pumps, vacuum pumps, oil pumps, sump pumps, etc. He is expected to care and perform minor repairs and service on that equipment. Packing glands and mechanical seals require lubrication or flushing with water to assure good operation. When shaft pump seals start leaking, the seal has to be completely replaced. Shaft packing can be adjusted with the packing gland nuts to insure a minimum of leakage from the pump. When there is excessive leakage due to packing or shaft wear, the packing has to be replaced, or the shaft has to be repaired. Bearings, unless they are completely sealed, need some form of lubrication. Follow the manufacturer's specifications for type of lubricant to use.

When bearings are worn, they should be replaced. If they are not replaced, damage to the shaft or bearing housing could result. The operator should take note of the general operating condition of each pump. Then, if a pump starts to drop in efficiency due to mechanical wear, it can be taken out of service for a general overhaul. Many plants will have a preventative maintenance schedule set up for all pump overhauls. Good care and service to pumps can extend there usefulness for many years.

References: *Elementary Steam Power Engineering*
Steam Plant Operation

Assignment:
1. What routine care is needed for packing glands on pumps?
2. What routine care is needed for mechanical shaft seals?
3. Discuss the lubrication requirements for pumps.
4. What causes shaft wear?
5. Why is it important to change worn bearings?
6. When should a pump be removed from service for a complete overhaul?

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